CONTRACT NO. NAS8-37137

VOLUME II
APPENDICES 2-5
PPIP, TRANSITION PLAN, AMOS PLAN
ENVIRONMENTAL ANALYSIS

(NASA-CR-183602) LIQUID ROCKET BOOSTER STUDY. VOLUME 2, BOOK 3, APPENDICES 2-5: PPIP, TRANSITION PLAN, AMOS PLAN, AND ENVIRONMENTAL ANALYSIS Final Report (General Dynamics Corp.) 208 p CSCL 21H G3/20

N90-10139

Unclas
0204307

LIQUID ROCKET BOOSTER STUDY
FINAL REPORT

GENERAL DYNAMICS
Space Systems Division

APPENDIX 2

PRELIMINARY PROJECT IMPLEMENTATION PLAN

PRELIMINARY

PROJECT IMPLEMENTATION PLAN

For the

Space Shuttle
Liquid Rocket Booster

Initial Submittal To:
NASA Marshall Space Flight Center
18 May 1988

GENERAL DYNAMICS
Space Systems Division

P.O. Box 85990
San Diego, California 92138

NOTE:

THIS APPENDIX CONTAINS DATA REQUIREMENT NO. 9, PRELIMINARY PROJECT IMPLEMENTATION PLAN.

Contents

Section	Subject	Page
1	**INTRODUCTION**	**1-1**
1.1	**Background**	**1-1**
1.2	**Purpose**	**1-1**
1.3	**Current Submittal**	**1-2**
2	**PROJECT MANAGEMENT**	**2-1**
2.1	**Management Approach**	**2-1**
2.1.1	Project Organization	2-1
2.1.2	Procurement	2-2
2.1.3	Project Control	2-7
2.2	**Project Schedules**	**2-9**
2.2.1	LRB Master Schedule	2-9
2.2.2	LRB Program Element Schedules	2-11
2.3	**Risk Assessment**	**2-11**
2.3.1	Technical Risk	2-11
2.3.2	Schedule Risk	2-13
2.3.3	Cost Risk	2-14
3	**SYSTEMS ENGINEERING AND INTEGRATION**	**3-1**
3.1	**Approach**	**3-1**
3.2	**System Requirements**	**3-1**
3.2.1	Ascent Performance	3-3
3.2.2	Intact Abort	3-4
3.2.3	Safety	3-5
3.2.4	STS Compatibility	3-6
3.2.5	Minimize Development and Life Cycle Costs	3-6
3.2.6	Evolution and Growth	3-7
3.3	**Systems Analysis**	**3-8**
3.3.1	Engine Analysis	3-8
3.3.2	Avionics Analysis	3-9
3.3.3	Facility Requirements Analysis	3-10
3.3.4	System Models	3-11
3.3.5	Logistics Analysis	3-12
3.3.5.1	Maintainability Analyses	3-12
3.3.5.2	Logistics Provisioning	3-13
3.3.5.3	Transportation and Handling	3-13
3.3.5.4	Training	3-14
3.3.5.5	Logistics Management Information Systems	3-14

3.4	**System Integration**	**3-14**
3.4.1	Requirements Management	3-15
3.4.2	Technical Analyses	3-15
3.4.3	STS Integration Support	3-16
4	**PRODUCT ASSURANCE**	**4-1**
4.1	**Approach**	**4-1**
4.2	**System Safety**	**4-2**
4.3	**Reliability**	**4-2**
4.4	**Maintainability Assurance**	**4-3**
4.5	**Quality Assurance**	**4-4**
5	**DESIGN AND DEVELOPMENT**	**5-1**
5.1	**Design Approach**	**5-1**
5.2	**Flight Hardware**	**5-2**
5.2.1	Structures	5-2
5.2.2	Separation System	5-3
5.2.3	Thermal Control	5-3
5.2.4	Propulsion	5-4
5.2.4.1	Engines	5-4
5.2.4.2	Engine Feed System	5-5
5.2.4.3	Pressurization	5-5
5.2.5	Electrical Power	5-6
5.2.6	Avionics	5-6
5.2.7	Orbiter and External Tank	5-7
5.3	**Ground Support Equipment (GSE)**	**5-7**
5.3.1	Factory	5-7
5.3.2	Testing	5-8
5.3.3	Transportation	5-8
5.3.4	Launch Site	5-9
5.4	**Software**	**5-9**
5.4.1	Schedules and Plans	5-9
5.4.2	Flight Systems	5-10
5.4.3	Ground Systems	5-10
5.5	**Advanced/New Technology Developments**	**5-11**
6	**MANUFACTURING**	**6-1**
6.1	**Approach**	**6-1**
6.1.1	Producibility	6-1
6.1.2	Make/Buy Philosophy	6-2
6.2	**Manufacturing Facilities**	**6-2**
6.3	**Manufacturing Control**	**6-3**
6.3.1	Methods	6-3
6.3.2	Planning	6-4

6.3.3	Tooling	6-4
6.3.4	Quality	6-7
6.4	**Flight Hardware**	**6-7**
6.4.1	Structures and Mechanisms	6-7
6.4.2	Separation System	6-9
6.4.3	Thermal Protection	6-9
6.4.4	Main Propulsion	6-9
6.4.5	Avionics	6-10
6.4.6	Electrical Power	6-10
6.5	**Assembly and Checkout**	**6-10**
6.6	**Ground Hardware**	**6-11**
7	**VERIFICATION**	**7-1**
7.1	**Approach**	**7-1**
7.2	**Verification Process**	**7-3**
7.2.1	Design Verification	7-6
7.2.2	Hardware/Software Verification	7-6
7.2.3	Verification Requirements Development	7-7
7.2.4	Verification Methods and Philosophy of Application	7-8
7.2.4.1	Analysis	7-8
7.2.4.2	Similarity	7-8
7.2.4.3	Inspection	7-9
7.2.4.4	Demonstration	7-9
7.2.4.5	Test	7-9
7.2.4.6	Prelaunch Operations	7-14
7.2.4.7	Flight Performance	7-14
7.2.5	Results Evaluation	7-14
7.2.6	Verification Completion	7-15
7.2.7	Verification Closeout	7-15
7.2.8	Customer Verification Closeout	7-15
8	**LAUNCH OPERATIONS**	**8-1**
8.1	**Introduction**	**8-1**
8.1.1	LRB Checkout and Flight Certification	8-1
8.1.2	Vehicle Integration	8-3
8.1.3	Integrated Vehicle Checkout and Launch Operations	8-4
8.2	**Scope**	**8-5**
8.2.1	Facility, LSE, and GSE Modifications	8-5
8.2.1.1	Mobile Launch Platform	8-6
8.2.1.2	Launch Pad	8-7
8.2.1.3	Vehicle Assembly Building (VAB)	8-9
8.2.1.4	LRB Checkout Facility	8-9
8.2.1.5	Launch Processing System	8-9
8.2.2	Operations Support	8-10
8.2.3	Verification and Validation	8-10

8.3	**Approach**	**8-11**
8.3.1	Modification Phase	8-11
8.3.2	Verification and Validation	8-12
8.4	**Launch Operations Integration**	**8-13**
9	**MISSION OPERATIONS SUPPORT**	**9-1**
9.1	**Scope**	**9-1**
9.2	**Mission Planning and Preparation**	**9-1**
9.2.1	Flight Test	9-1
9.2.1.1	Flight Test Requirements	9-2
9.2.1.2	Flight Envelope Expansion	9-3
9.2.1.3	Flight Test Analysis and Reporting	9-3
9.2.1.4	Flight Test Instrumentation	9-4
9.2.2	Mission Design	9-5
9.2.2.1	LRB Mission Capabilities and Constraints	9-5
9.2.2.2	Mission Design Support	9-6
9.2.3	Mission Assessment	9-7
9.2.4	Flight Readiness Review	9-8
9.3	**Mission Analysis**	**9-9**

1
INTRODUCTION

1.1 BACKGROUND

This *Preliminary Project Implementation Plan (PPIP)* has been developed by General Dynamics as part of a NASA Phase A study examining the feasibility of replacing the current Solid rocket Boosters on the Space Shuttle with Liquid Rocket Boosters (LRBs). Plans such as this are typically prepared during the later phases of a project, but the PPIP is warranted in this case due to the need to determine the implications of integrating the LRB with the Space Transportation System at the earliest practical date.

1.2 PURPOSE

The ultimate purpose of the LRB Project Implementation Plan (PIP) will be to identify and define all elements required in a full scale development (FSD) program for the LRB. The purpose of this preliminary plan is to provide management level visibility of the FSD phase program as planned by the study contractor, to the extent possible during a Phase A study of a program of this complexity. Its submittal satisfies the Data Requirement (DR)-9 specified for this study. The PPIP will be updated periodically until the end of Phase B, when it will be formally approved by General Dynamics and NASA as the final Project Implementation Plan. From that time hence, it will serve as the principal reference guide for management of the LRB program, addressing such requirements as design and development, configuration management, performance measurement, manufacturing, product assurance and verification, launch operations, and mission operations support.

1.3 CURRENT SUBMITTAL

This document is the initial submittal of a draft PPIP, delivered to the NASA Marshall Space Flight Center (MSFC) in May 1988. After NASA review and comment, an updated version of the PPIP will be submitted in July 1988 along with the final report of the Phase A study.

2
PROJECT MANAGEMENT

2.1 MANAGEMENT APPROACH

General Dynamics' approach to the management of the Liquid Rocket Booster (LRB) program is aimed at achieving the principal objective of the program — enhancing the safety and performance of the Space Transportation System (STS) — at the lowest possible cost and with minimal disruption to STS operations. We feel there are three vital elements to accomplishing this goal: careful up-front planning, encouragement of communication at all levels of the organization, and use of the best available management support tools and technologies.

2.1.1 PROJECT ORGANIZATION

General Dynamics Space Systems Division (GDSS) was established in March 1985 to improve the corporation's ability to effectively manage space programs. GDSS utilizes a matrix management system wherein programs such as LRB are staffed primarily by personnel with permanent reporting relationships to home functional departments, such as Engineering, Production, and Finance. Only the LRB program manager and certain members of his staff are likely to be permanent employees of the LRB program office. This arrangement enables programs such as LRB to make the most effective use of the personnel assigned to the program and permits employees on such programs to tap into the broader resources of their home functional departments as needed.

Since this is a preliminary plan developed during Phase A of the LRB program, it is too early to identify the specific personnel or reporting relationships that will be established for the full scale development phase of the project. If the program is managed within Space Systems Division, the program manager will in all likelihood report directly to the division general manager, who currently reports directly to the president of the corporation. An alternative option that will be considered during Phase B of the program will be to establish a separate division to implement the LRB program. In this case, the LRB program manager would be expected to report to the president of the corporation or one of the president's staff members.

The LRB program manager will be supported by a deputy program manager and can be expected to have several key personnel reporting directly to his office. The staff positions that typically report directly to the manager of a project such as LRB include a chief engineer, a manufacturing manager, a colocated product assurance and safety representative, a program control manager, and an administrative officer.

The LRB project will be organized according to the program Work Breakdown Structure (WBS). A preliminary WBS for the LRB program is shown in Figure 2-1. Each functional organization supporting the LRB program will be assigned responsibility for certain WBS elements, and will receive a separate budget for each WBS element that it must support. Each organization will further subdivide its tasks into discrete work packages that will receive specified portions of the organization's budget. The WBS will also align the working level interfaces between our LRB organization and the NASA project office responsible for managing the LRB project.

2.1.2 PROCUREMENT

It will be the LRB prime contractor's responsibility to develop a Make/Buy Plan that best utilizes its capabilities and those of its subcontractors. This is vitally important for achieving a high quality product at the lowest possible cost. General Dynamics' many

WORK BREAKDOWN STRUCTURE INDEX
FOR THE
LIQUID ROCKET BOOSTER

LEVEL	WBS	ELEMENT TITLE
		Total Project
1	00-00-00	Liquid Rocket Booster Program
		Hardware Elements Dimension
2	01-00-00	Liquid Rocket Booster
3	01-01-00	Structures & Mechanisms
4	01-01-01	Oxidizer Tank
4	01-01-02	Fuel Tank
4	01-01-03	Intertank Adapter
4	01-01-04	Forward Adapter
4	01-01-05	Thrust Structure
4	01-01-06	Aft Adapter
4	01-01-07	Avionics Installation
4	01-01-08	Launch Hardware
4	01-01-09	Pressurization
4	01-01-10	Nose Fairing
3	01-02-00	Separation System
3	01-03-00	Thermal Protection
4	01-03-01	Tank
4	01-03-02	Body
3	01-04-00	Main Propulsion
4	01-04-01	Expendable Engines
4	01-04-02	Reusable Engines
4	01-04-03	Propellant Feed System
4	01-04-04	Engine Actuators
3	01-05-00	Avionics
4	01-05-01	Guidance, Navigation, & Control
4	01-05-02	Instrumentation & Data
4	01-05-03	Communication & Tracking
4	01-05-04	Range Safety
3	01-06-00	Electrical Power
4	01-06-01	Power Distribution Unit

Figure 2-1. LRB Work Breakdown Structure.

WORK BREAKDOWN STRUCTURE INDEX
FOR THE
LIQUID ROCKET BOOSTER

LEVEL	WBS	ELEMENT TITLE
		Hardware Elements Dimension (cont'd)
4	01-06-02	Cabling & Harness
4	01-06-03	Batteries
3	01-07-00	Recovery System
2	02-00-00	Orbiter
3	02-01-00	Avionics
4	02-01-01	Guidance, Navigation, & Control
4	02-01-02	Controls, Displays, & Instrumentation
4	02-01-03	Communications & Data
4	02-01-04	Data Management
2	03-00-00	External Tank
3	03-01-00	Flight Hardware
2	04-00-00	Facilities
3	04-01-00	Manufacturing
3	04-02-00	Test
3	04-03-00	Launch
3	04-04-00	Mission
3	04-05-00	Recovery
		Phase & Function Dimension
1	1000	Liquid Rocket Booster - Phase & Function
2	1100	DDT&E
3	1110	Program Management
3	1120	Engineering
4	1121	Systems Engineering & Integration
4	1122	Design & Development
3	1130	Ground Support Equipment
3	1140	Manufacturing
4	1141	Initial Tooling
4	1142	Initial Spares
3	1140	Test
4	1141	Ground Test
4	1142	Flight Test
4	1143	Test Operations

Figure 2-1. LRB Work Breakdown Structure (Continued).

WORK BREAKDOWN STRUCTURE INDEX
FOR THE
LIQUID ROCKET BOOSTER

LEVEL	WBS	ELEMENT TITLE
		Phase & Function Dimension (cont'd)
2	1200	Production
3	1210	Program Management
3	1220	Sustaining Engineering
3	1230	Manufacturing
4	1231	Sustaining Tooling
4	1232	Flight Hardware
4	1233	Final Assembly & Check-out
2	1300	Operations
3	1310	Operations Support
4	1311	Program Support
4	1312	Spares Procurement
4	1313	Mission Control
3	1320	Launch Support
4	1321	Ground Operations
4	1322	Propellant Operations
4	1323	Other Operations

Figure 2-1. LRB Work Breakdown Structure (Continued).

years of experience as prime contractor for the Atlas and Centaur programs will be drawn upon as required to rapidly develop an effective Make/Buy Plan.

Recent corporate initiatives will enhance General Dynamics' ability to develop and implement a procurement strategy that helps meet the goals of the LRB program. As part of a corporate-wide program to improve the company's competitiveness, procurement policies have undergone a thorough review, with emphasis on renewing our commitment to obtain goods and services from our vendors and subcontractors at the lowest possible cost. More specifically, several major steps were taken by Space Systems Division in the 1987-88 time frame to improve its ability to make the most effective use of subcontractors in the production of launch vehicles. These included: establishment of the Commercial Atlas/Centaur program, implementation of an extensive factory modernization program, and the setting up of additional production facilities at remote locations to reduce the cost of acquiring certain launch vehicle components.

To enhance the specific procurement practices of the LRB program, several steps will be taken. These will include:

a. Identification of subcontractors and involvement of them in our activities as early in the program as practical.

b. Establishment of innovative incentive programs to acquire LRB subsystems, components, and piece parts at the lowest possible cost.

c. Establishment of state-of-the-art receiving and inventory control capabilities at the LRB final assembly site.

2.1.3 PROJECT CONTROL

Project control for the LRB program will be supported by General Dynamics' SIMS-II system, the cornerstone of our performance and cost reporting system. Installed in January 1987 to provide a basic management support tool, SIMS-II is a computerized system used at all levels to help organize and plan the scope of work. It provides information for planning, assessing task accomplishment, evaluating cost and schedule performance, analyzing trends, and projecting requirements. It is a well documented and proven management system for planning and controlling contractual tasks. It is the standardized management system applied to nearly all contracts at General Dynamics Space Systems Division and was validated by the U.S. Air Force as meeting all requirements of DODI 7000-2 on 15 July 1987.

The application of SIMS-II to the LRB program will provide information necessary for preparation of any required NASA 533s as well as our own internal management reports. SIMS-II is fully compliant with program cost and schedule reporting requirements on other large NASA programs. It is documented in the directive manuals of the Space Systems Division and is subject to periodic examination by the General Dynamics Corporate Internal Audit function. These financial practices are performed with the approval and constant surveillance of in-plant government representatives. These agencies review Space Systems Division financial information for allowable costs under regulations of NASA and other government agencies.

General Dynamics has evolved a financial management system based on utilization of the program Work Breakdown Structure (WBS). As explained in Section 2.1.1, all activity on the LRB program will be oriented to the WBS to ensure integration of cost with tasks. Our SIMS-II accounting system will provide for accurate tracking of all direct and indirect costs applicable to the program. The cost accumulation (work order) structure will provide integration of WBS and cost tracking at any level of the WBS or functional organization.

The ten digit work order (AWO) numbers for a contract are developed in a logical sequence within the cost accumulation structure following the WBS structure. These AWOs are controlled by entry into a computerized master file only when authorized by a sales order. The four digit department number is used to identify the organization incurring the cost.

Cost baseline budgeting is initally accomplished by planning the hours and non-labor cost elements through the period of performance. These are entered into the SIMS-II system and a dollarized time-phased budget document is produced. Work Authorization Plans (WAPs) are prepared to describe all tasks and are fed into the SIMS-II system. WAPs define task effort in hours by months and milestones which define task progress. Hours planned are partitioned into active and planning packages which support project planning. WAP tasks are at the functional group level and lowest WBS level for each task.

All changes to the plan must be authorized by the GDSS program manager and conform to the authorized contract plan. Changes to budgets are made as modifications to the WAPs and entered into SIMS-II. As scheduled milestones are accomplished, the budgeted value is reflected as earned value. SIMS-II summarizes budget, earned value, actual cost, and forecast data from cost accounts through the WBS to produce totals at any required level. Our monthly Performance Measurement Report (PMR) provides comparative values for planned work performed, planned cost, and actual cost. The PMR also calculates variances to plan.

The PMR and budget baseline reports are provided to each program on a monthly basis. This provides an early warning of potential problems. Use of the PMR allows these problems to be pinpointed as to WBS and functional department.

2.2 PROJECT SCHEDULES

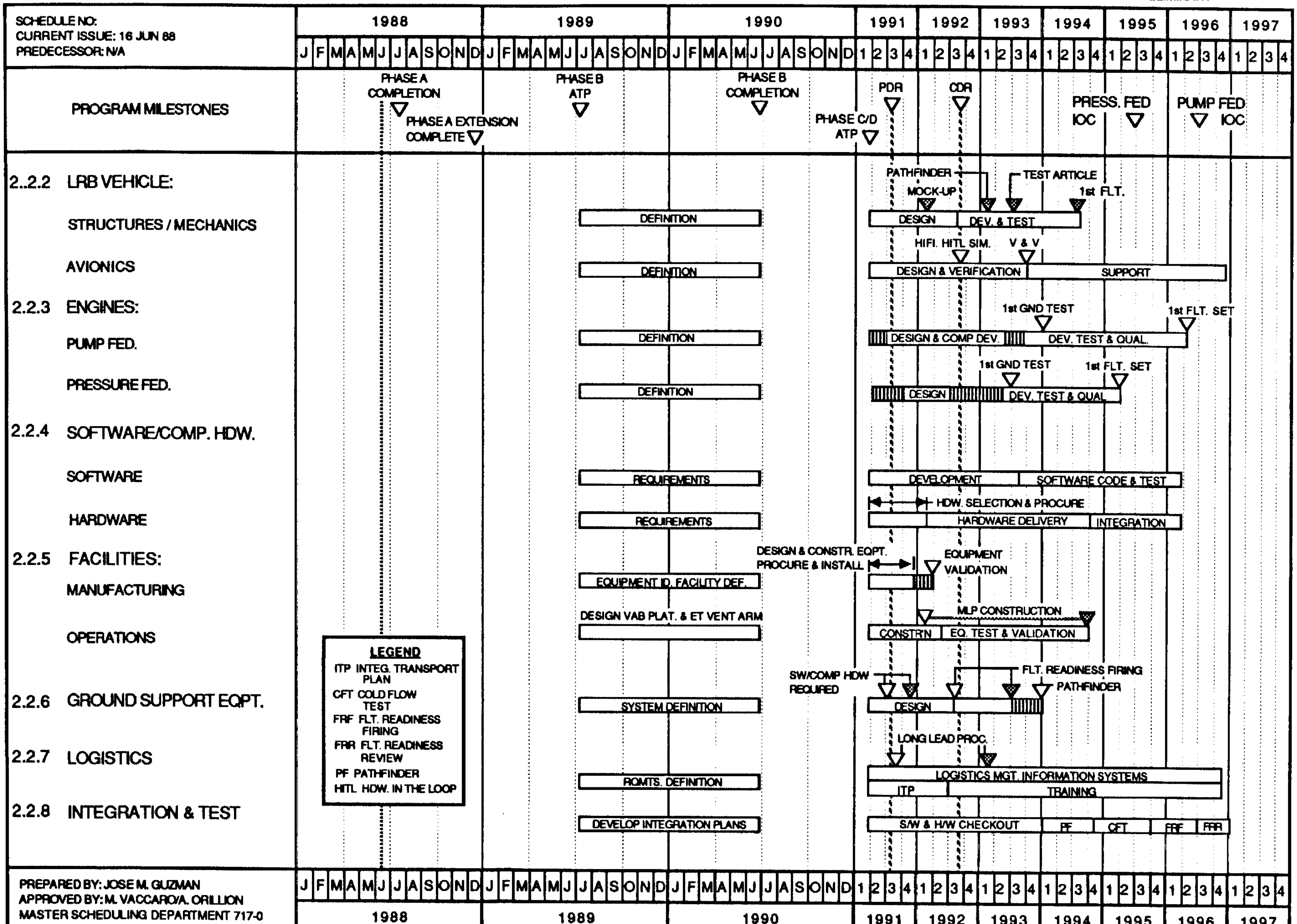
Since the objective of the LRB program is to enhance the performance and safety of a launch system that is already operational, timely implementation of the LRB program is particularly vital to its success. Using the SIMS II system described above, LRB program milestones can be achieved in a timely manner without compromising safety or performance. LRB schedules will be developed from contract requirement milestones progressively downward through all levels of the WBS. These will be directly related to the WBS task to provide realistic schedules for first-line work authorization documents. The schedule will reflect the major milestones as identified by NASA. Task accomplishment is keyed to the milestones where applicable.

2.2.1 LRB MASTER SCHEDULE

A preliminary LRB project master schedule is shown in Figure 2-2. Since a final selection between pump-fed and pressure-fed LRBs has not yet been made, this schedule shows engine development milestones for both concepts; development time required for the pressure-fed engine is about one year shorter. The schedule also illustrates General Dynamics' view that the LRB project should be implemented as rapidly as possible; we show a relatively short (one year) Phase B beginning in the second quarter of calendar year 1989, followed immediately by Phase C/D. This will require competition for LRB full scale development during the latter half of Phase B. This is an unusual approach for NASA programs, but has been used for Air Force space programs, most recently in the transition from Concept to Validation phases on the Advanced Launch System program.

2.2.1 LRB PROJECT MASTER SCHEDULE

PRELIMINARY



2.2.2 LRB PROGRAM ELEMENT SCHEDULES

Figures 2-3 through 2-6 show schedules for various LRB program elements. These schedules are all preliminary, as would be expected at this early phase, and will be updated as the program matures.

2.3 RISK ASSESSMENT

The key to successful risk management is awareness. Our three-point approach to minimizing risk impact consists of:

a. Identification, through an engineering and management work force sensitive to the need for early recognition and reaction to potential problems.

b. Avoidance where possible, through selection of proven approaches. Major trades related to risk are expected to be complete prior to initiation of full scale development.

c. Managing, through comprehensive planning and review, with consideration for alternate (backup) approaches, and schedule or budget reserves.

This general approach is common to all risk categories, though the specific techniques and tools may differ.

2.3.1 TECHNICAL RISK

At this time there are few major technical risks anticipated in LRB development. This is primarily because our program strategy is to minimize risk by utilizing existing, *Figures 2-3 Through 2-6. LRB Schedules (To be provided in final PPIP submittal).*

proven technologies wherever possible. Potential areas in which risks might evolve include:

a. Need for new technology development. Ablative engine cooling and welding processes for thick aluminum/lithium structures are examples of advanced technologies that could result in added technical risk. As such new technology needs are identified, we will develop specific plans to minimize the potential for program impacts. Drawing upon the expertise available in the country, our plans will evaluate and select approaches, quantify risks, and establish appropriate schedules, budgets, and review processes.

b. Aerodynamic interaction effects. Wind tunnel tests prior to full-scale development should minimize potential impacts. The test techniques and aerodynamic data base established in Space Shuttle work to date add significant confidence that changes resulting from incorporating the LRB can be accomplished at low risk.

2.3.2 SCHEDULE RISK

Planning, aided by use of our computerized scheduling system, will be used to establish realistic schedules. Use of this scheduling system in conjunction with our Performance Measurement System will provide the insight to identify trends in time to take effective action. Critical path analyses will be performed to identify those tasks that are most critical to achieving program milestones.

The most significant schedule risk is integration of the LRB into launch site operations. The launch pad and Vehicle Assembly Building (VAB), which will be in use for STS operational flights, will require modification for LRB compatibility. Tying up these facilities for LRB modifications could impact STS launch schedules.

Our approach to minimizing this risk is to emphasize the early definition of interface requirements to support those modifications. The maturity of the STS launch operation provides a good base against which we can develop firm requirements to be accommodated by the launch site facilities. In addition, we recommend that NASA consider the use of "modkits" to reduce facility down time, and early incorporation of the mods prior to the 1994-1995 time frame, when the STS flight rate is expected to peak. More detailed descriptions of launch site modifications required to support LRB are contained in Section 8 of this plan and Appendix A: SRM/LRB Transition Plan.

2.3.3 COST RISK

Cost risk occurs most often as a result of of poorly defined cost estimates, changes in requirements, or problems deriving from technical or schedule risks. Our approach to minimizing cost risk is to emphasize the development of accurate and realistic cost estimates from the earliest stages of the program onward. The maturity of the Space Shuttle program and our experience manufacturing and launching the Atlas booster (similar in many regards to the pump-fed LRB) provide a reasonably good basis for establishing sound cost estimates. We have already begun the process of calibrating our existing booster cost models by testing them against the NASA Shuttle cost models and actuals.

The Space Shuttle provides a similarly valid base for development of LRB requirements, which is key to reducing the probability of incurring expensive design or procedural changes downstream. In concert with the LRB project goals of maintaining compatibility with the existing Shuttle flight vehicle and operations, we consider our requirements baseline to be much more firm than in the case of a new launch vehicle. The LRB program control manager responsible for cost performance will have authority to take all reasonable steps required to meet cost targets. Our experience on design-to-cost programs such as the Space Shuttle mid-fuselage and Space Station will help ensure that we are organized effectively for the minimization of cost risk. This combination of proven estimating techniques and sound management controls will provide the basis for effective LRB cost control.

3
SYSTEMS ENGINEERING AND INTEGRATION

3.1 APPROACH

Integration responsibilities of the LRB prime contractor include definition and refinement of system requirements, development of compatible interface designs, support for the development of an integrated STS system verification program, and support for the development of launch site operations. The role of the systems integrator on this program is especially critical due to the LRB's integration into an existing manned launch system. GDSS will actively participate with the NASA/Marshall Space Flight Center (MSFC), other NASA centers involved in the project, and the STS integration contractor to minimize requirements for STS modifications.

The relationship of the General Dynamics LRB Project Office with the NASA/MSFC Project Office and the STS systems engineering and integration (SE&I) activity is shown in Figure 3-1. We recognize the importance of early identification and resolution of systems integration issues and will support the STS technical panels in this process. Such support will continue on an as-required basis through LRB flight testing. As part of this support we will make available the LRB design data that reflect the sensitivity of the LRB to such requirements as size, environments, loads, and interface conditions.

3.2 SYSTEM REQUIREMENTS

A vital early task of the LRB prime contractor will be to define the LRB system,

NSTS PROGRAM
NSTS SYSTEMS ENGINEERING & INTEGRATION RELATIONSHIPS

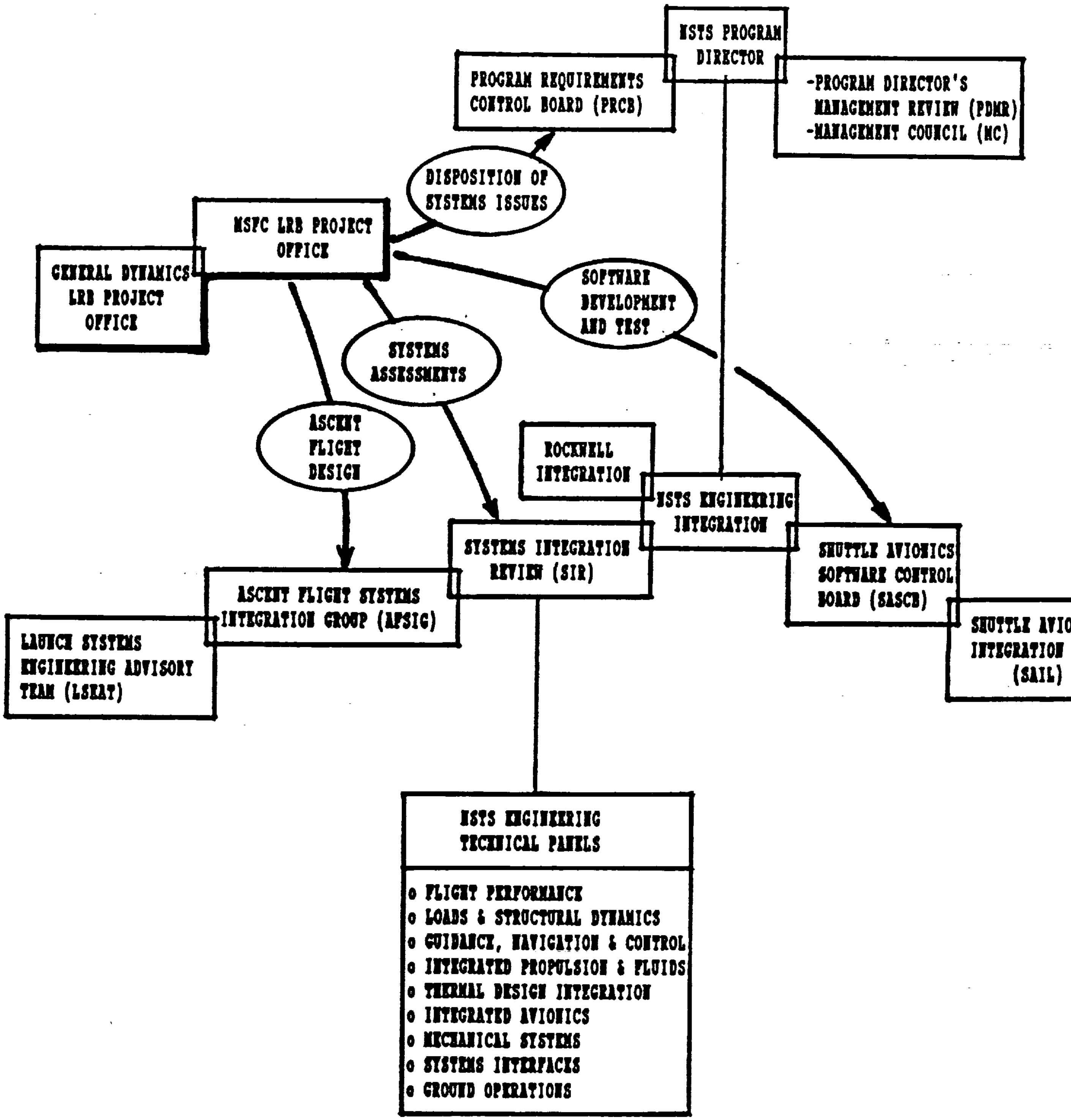


Figure 3-1. STS systems engineering and integration relationships.

design, configuration, and operational requirements. As shown in Table 3-1, there are a large number of complex factors that must be considered in the derivation of basic LRB characteristics such as diameter, length, number of engines, and mass properties. Major LRB system requirements that will drive the vehicle design and operational procedures are summarized below.

Table 3-1. Examples of factors that can influence LRB design.

LRB Characteristic	Examples of Influencing Factors
LRB Diameter	• Proximity to Orbiter and ET • Aeroheating effects on Orbiter and ET thermal protection system (TPS) • Utilization of existing ET interface fittings • Modification requirements for the mobile launch platform (MLP) • Orbiter aerodynamic wing loads
LRB Length	• Aeroelastic effects • LRB/ET forward attach loads • Stability and control • Modification requirements for KSC facilities/GSE
Number of Engines	• Thrust vector control (TVC) authority • Abort options • MLP flame hole modifications • Startup/shutdown sequence • Safety/Reliability
Mass Properties	• Propellant tank arrangement • TVC authority • LRB/ET interface loads

3.2.1 ASCENT PERFORMANCE

The primary groundrules currently being utilized in the development of the LRB ascent performance capabilities are:

- Provide capability to launch 70,500 pounds to 150 nm orbit.
- Provide safe abort capability with one LRB or SSME engine out with a self-imposed goal of abort to 105 nm orbit with one engine out.
- Abide by flight constraints such as maximum dynamic pressure, q alpha profiles, launch probabilities, and performance reserves.

It is anticipated that NASA will perform trajectory simulations and wind tunnel testing of the integrated vehicle with variations of the configuration and performance parameters incorporated into the test activities. These test and simulation results will be used to assess the impact of the LRB performance capabilities. The NASA LRB Project Office will support these activities by providing the prime contractor with STS flight data, including configuration and mass properties data, propellant distribution and consumption profiles, engine performance characteristics, thrust vector control authority constraints, aeroelastics effects, and other necessary data as requested.

3.2.2 INTACT ABORT

Crew safety and mission success are primary drivers in the design of the LRB. The basic requirement concerning abort is to provide intact abort capability at any time during the launch profile from liftoff through first stage burnout with one engine out. GDSS has established the additional goal of providing the capability to abort to a 105 nm circular orbit with one engine out at any time during the launch profile. The LRB Project Office will support the Ascent Flight Systems Integration Group (AFSIG) and Abort Panel in performing any required integrated vehicle wind tunnel testing, trajectory simulations, and/or analyses of first stage abort options.

3.2.3 SAFETY

The LRB program will adhere to all NASA STS safety guidelines, including those set forth in NHB 5300.4 (1D-2) "Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program" (see Section 4 of this volume). The LRB will be designed to meet STS fail safe requirements and will emphasize design conservatism in areas identified as having critical failure modes. Two areas requiring special attention are propellant management and engine health verification prior to lift-off. The LRB may utilize propellants different than those used on the Shuttle, placing new safety requirements on KSC for propellant storage, handling, and servicing. The LRB prime contractor will work with the STS Ground Operations Panel (GOP) and KSC safety personnel in defining and implementing these new requirements on the KSC facilities and personnel.

Verification of engine health prior to lift-off is a primary safety issue and is envisioned to be accomplished in a manner similar to that currently used for the SSMEs. LRB safety personnel will assess the procedures to be used as the engine ignition sequence and thrust buildup characteristics are better defined.

Other NSTS systems engineering areas that will be supported by LRB safety as required include:

- Evaluation of LRB interfaces with other Shuttle elements to identify failure modes affecting crew safety or mission success.
- Preparation of Shuttle System Element Interface Functional Analysis (EIFA) Documents.
- System level reliability analyses that affect LRB element interfaces.
- Support system level hazard analyses by assessing LRB hazard analyses and operations data, failure modes and effects analyses (FMEA), and safety study results.
- Identification and preparation of safety requirements for LRB integrated tests.

• Support system level safety studies and, if required, accident/incident investigations.

• Definition of a flight termination system that complies with AFETRM 127-1 and SAMTECM 127-1.

3.2.4 STS COMPATIBILITY

A major design requirement to be adhered to in the development of the LRB configuration is to assure compatibility with the Orbiter, ET, and KSC facilities. This imposes design constraints and verification requirements that would not be present in the development of a stand-alone launch system. Specific groundrules and design goals that have been established thus far include: (1) no redesign of the Orbiter or ET structures or thermal protection systems, (2) maximize commonality with existing STS elements (e.g., SRB avionics) where cost-effective, and (3) minimize modifications to software, GSE, and ground support facilities.

These groundrules will be assessed in conjunction with the trajectory simulations and wind tunnel testing of the integrated vehicle discussed in Section 3.2.1. These test and simulation results will be evaluated to determine the impact of the LRB configuration on such launch and flight considerations as aerodynamic flow and thermal heating in the proximity of the Orbiter wing and ET, LRB/ET attachment interface loads, and the geometric relationship with the MLP flame hole, holddown posts, access platforms, and swing arms.

3.2.5 MINIMIZE DEVELOPMENT AND LIFE CYCLE COSTS

While safety and performance issues are preeminent in the design and development of the LRB, development of a cost-effective LRB concept is critical to final approval and continued success of the program. In fact, the primary rationale for minimization of STS impacts is to avoid the significant costs that would be incurred in making major changes to that would invalidate the already verified Shuttle system. Cost is therefore a principal trade study evaluation criterion and will continue to be of paramount concern throughout the design and development phases of the program. Among competing LRB design concepts that meet safety, reliability, and performance goals, it is expected that development cost and life-cycle cost will be the most commonly used figures of merit to arrive at preferred design solutions. As the LRB design matures and cost modeling evolved from a parametric to a detailed estimating methodology, the SE&I process will be supported by cost estimates of improved fidelity.

Once the preferred LRB design is selected, emphasis will shift from the use of cost as a trade study criterion to the achievement of effective cost management at all levels of the program. Reducing costs through such means as innovative production techniques, commonality, reduced test requirements, and utilization of existing hardware and technology will be emphasized throughout the LRB development. This will require the development of a management system that integrates all aspects of program information essential to program planning, control, cost estimation, and cost control. The LRB Work Breakdown Structure (WBS) will serve as the framework for all cost modeling and cost control activities throughout the life of the project. A more detailed discussion of cost management activities is contained in Section 2 of this plan.

3.2.6 EVOLUTION AND GROWTH

A system requirement that is likely to increase in significance over time is development of a capability for LRB evolution and growth. In addition to functioning as an element of the existing STS, the LRB could be used as an element of the Advanced Launch System, growth versions of the STS, or as a stand-alone expendable booster. Use of the LRB for such applications would not only increase the overall utility of the system, but could also permit increases in production rate for LRB elements, which could reduce the cost of the basic STS application. Applicability of LRB concepts for these growth missions is therefore an additional consideration in trade studies and in the definition of the overall time-phased LRB system.

3.3 SYSTEMS ANALYSIS

The complexity of integrating the LRB into the existing STS will require a special commitment on the part of the LRB prime contractor to conduct thorough systems analysis, which will in turn require in-depth knowledge of the design and operation of the Space Shuttle system. Understanding how these STS functions will change with the replacement of SRBs by LRBs will be the primary objective of the systems analysis conducted to support this program.

3.3.1 ENGINE ANALYSIS

The LRB prime contractor shall perform LRB systems analyses with a primary objective of defining LRB engine performance capabilities and constraints, with emphasis on ensuring compatibility with existing STS elements. This includes determining the compatibility of the LRB interfaces with the KSC facilities and equipment, SRB avionics, Orbiter and ET software, and ET structural interface attachments. Analyses will be performed on the LRB engine to define the performance characteristics required to support the systems analyses, tests, and simulations being performed on the integrated vehicle. This includes defining the engine characteristics for thrust buildup/shutdown, throttling, Isp verification, and thrust vector control.

Extensive trajectory simulations and wind tunnel testing will be required to define the LRB engine operating profile from pre-ignition through first stage shutdown. High fidelity flexible body analyses may also be required to assess the engine startup and shutdown phases. Since liquid engines have throttling capability, this approach may be considered to minimize vehicle structural loads during critical trajectory phases, such as the initial roll maneuver, high q boost, post-high q boost, and pre- and post-staging. Throttling will also be considered in first stage abort conditions. The results of these additional tests and simulations will be used to define:

- Engine throttling requirements.
- Base drag and plume effects.
- Ignition startup sequence.
- First stage shutdown sequence.
- Procedure for performing engine health check during ignition.
- Engine-out effect on abort options.
- Booster separation motor (BSM) sizing.
- Inputs to SAIL test requirements.
- Engine test stand requirements.
- Updates to loads model, trajectory profile, thermal design requirements, and vehicle performance.
- Inputs to MLP holddown design requirements.

Once the LRB preliminary design has been baselined and vehicle and engine development progresses, data will be provided to support the ongoing wind tunnel testing, trajectory simulations and structural analyses, such as: mold line refinements in the nose cone and aft skirt areas; mass properties; BSM characteristics; and engine thrust, throttling, startup, and shutdown characteristics.

3.3.2 AVIONICS ANALYSIS

The approach to development of the LRB avionics system is to minimize the impact on the Orbiter avionics system by utilizing the current SRB/Orbiter interface design. However, the liquid engine will have additional interface requirements, such as engine control (startup, shutdown, throttling, and health checks) and fuel/oxidizer pressure control. The current approach is to design a single fault tolerant autonomous system that will utilize the current SRB/Orbiter interface format. The design options will be coordinated with the Integrated Avionics Panel and will provide support as required to the Shuttle Avionics Integration Laboratory (SAIL), Shuttle Avionics Software Control Board (SASCB), Orbiter Avionics Systems Control Board (OASCB). This activity will also include coordinating the instrumentation provisions at the LRB/ET interface that are required to support flight test and operations requirements.

3.3.3 FACILITY REQUIREMENTS ANALYSIS

The current approach to LRB final assembly and integrated checkout is to perform these tasks at the manufacturing facility if possible. This would permit the LRB to be shipped directly to KSC and installed on the MLP. However, this requires a manufacturing/transportation/storage concept similar to the ET. These study results will be coordinated with the Ground Operations Panel and applicable KSC organizations to assist in the development of the ground and launch operations requirements for the LRB. A more detailed discussion of manufacturing and assembly requirements is contained in Section 6 of this plan.

The KSC ground systems and operations philosophy is to utilize current facilities and equipment to the maximum extent possible with minimum modifications. However, the LRB has significant differences from the SRB that will affect ground support requirements and facilities, including:

- Larger diameter and greater length.
- Liquid propellant storage.

• Assembly prior to installation on the mobile launch platform (MLP).

This will require the LRB ground operations activity to be assessed from manufacturing through launch. Changes that may be required to the ground support system as a result of these new characteristics and requirements include:

• Redesign holddown release system to reduce vehicle liftoff loads.
• Increases in MLP flame hole dimensions and nozzle clearances.
• Reduced assembly provisions in the Vehicle Assembly Building (VAB).
• VAB work platform modifications.
• Pad venting modifications.
• On-pad propellant loading modifications.

Additional discussion of KSC facility requirements is contained in Section 8 of this plan.

3.3.4 SYSTEM MODELS

The LRB Project will support STS systems integration in the development and updating of the math models used to support the ascent flight design activities, primarily in the areas of loads, aerodynamics, hydraulics, propulsion, consumables, environment, and ground and flight simulations. Specific analyses to be performed and models to be utilized will include:

• Interfaces with ET and MLP and the effect of engine startup and pad release.
• Interfaces with ET and effect of engine-out during ascent and engine shutdown at first stage burnout.
• Acoustic and overpressure effects on launch vehicle at engine ignition.
• Aerodynamics flow effects on ET, Orbiter, and mated configuration.
• Base drag and plume effects on ascent performance.

- Booster separation modeling, clearance verification, and system definition.
- Integrated hydraulics/thrust vector control.
- Propellant loading and consumption.
- Aerothermal effects on ET and Orbiter.
- Cryogenic propellant loading effects.
- Shuttle Avionics Integration Laboratory support (e.g., GN&C simulations, lift-off clearances, and separation dynamics).
- MSFC-mated element system (MMES) simulations.
- Launch Processing System (LPS) simulations.
- Detailed modal survey.
- Failure mode analyses.
- Overall stress analysis.

3.3.5 LOGISTICS ANALYSIS

To ensure that the LRB can be operated in a reliable and cost-effective manner, a variety of logistics-related analyses must be performed, beginning in the earliest phases of the program.

3.3.5.1 Maintainability Analyses

Maintainability analyses will be performed to assure that LRB flight systems and their line replaceable units (LRUs) are accessible for maintenance. LRUs will be located and access provided such that minimum time is required to replace or service them during vehicle element buildup, verification, and assembly. The LRB will be capable of alignment, connection, inspection, and verification of mechanical and electrical interfaces during mating operations. The mated LRB will be capable of checkout after ground system connection on the launch pad. Accessibility to equipment installations, element interfaces, and service umbilicals requiring inspection, servicing, installation, or verification will be provided.

To ensure maintainability, development of any new ground support equipment or facilities will be conducted with full consideration of such factors as fault isolation, ease of replacement of failed components, and operating manpower requirements. Mockups, simulators, and actual Shuttle operating experience will be utilized to support LRB maintainability analyses.

3.3.5.2 Logistics Provisioning

The LRB logistics activity will support the STS integrated logistics activity in the following areas:

- Support Shuttle Integrated Logistics Panels (ILP).
- Support system supply support planning in spares selection and operational phase planning.
- Spares inventory, overhaul capability, logistics capabilities.

3.3.5.3 Transportation and Handling

Transportation and handling analyses will be performed to assure that the LRB can be transported from its assembly site to its final launch position without degradation of reliability. Analyses will be performed to assure that the LRB size and weight does not exceed the limitations of feasible transportation and handling systems, that no damaging loads are induced in the LRB during transportation and handling, and that the LRB is adequately protected against natural environments during transportation and handling.

3.3.5.4 Training

Trained and certified personnel must be available to support the LRB from the time it leaves the manufacturing facility until liftoff from the pad. It will be the responsibility of the LRB prime contractor to support the training and certification of these personnel in the areas of LRB handling, transportation, maintenance, repair, overhaul, testing, and checkout. The LRB contractor must also support the training of flight crews, flight controllers, and other personnel required to support simulator and laboratory facility activities involving the LRB.

3.3.5.5 Logistics Management Information Systems

The LRB logistics system will be structured to be compatible with the STS integrated logistics system and will support the integrated logistics verification information system that provides program level visibility over major logistics activities. This will include the identification and status of the LRB logistics support posture, constraints, issues, and potential problem areas.

3.4 SYSTEM INTEGRATION

To meet the challenge of integrating the LRB successfully with the existing Space Shuttle system, the LRB prime contractor will have to work closely with several NASA centers and the STS integrating contractor to identify and meet all integration requirements within the program constraints. This will include careful requirements management to assure that all compatibility issues are addressed, performance of the technical analyses required to develop an LRB design concept that is fully compatible with the rest of the Shuttle system, and continuing cooperation between the LRB contractor and the rest of the STS team throughout all phases of implementation.

3.4.1 REQUIREMENTS MANAGEMENT

The LRB Contract End Item Specification (CEI) will be compatible with the applicable requirements specified in NSTS 07700, Volume X, *Space Shuttle Flight and Ground System Specification,* and the related system level integrated schematics, interface control documents (ICDs), and test and verification requirements. All requirements in the LRB CEI Specification will be traceable to Volume X. Conversely, the element level system/subsystem specifications, integrated schematics, interface control documents, and the LRB Master Verification Plan will be traceable to the LRB CEI. All of these categories of documents will be maintained and controlled by the LRB configuration management system, which will be developed and implemented to meet the requirements of NSTS 07700, Volume IV, *Configuration Management.* This will include providing support to the evaluation, maintenance, and updating of the applicable system level specifications, ICDs, and integrated schematics.

3.4.2 TECHNICAL ANALYSES

The LRB Project will support the STS mission planning and operations by performing LRB technical analyses required to support each STS mission. This will include the development, for each STS flight, the LRB mass properties, engine "tag" values, propellant loading tolerances, assessment of engine operating power levels, and resolution of anomalies from previous flights. Support will also be provided for post-flight activities to reconstruct LRB ascent performance for comparison with that predicted and to evaluate any in-flight anomalies. These activities will continue to be performed in depth until completion of the flight test program and the removal of the development flight instrumentation.

3.4.3 STS INTEGRATION SUPPORT

As the LRB continues through the development and verification activities toward first flight, support will continue to be provided to the STS program level and systems integration activities, especially as it relates to integrated vehicle performance verification, interface definition, flight instrumentation requirements, ground systems and operations development and verification, configuration control, safety, reliability, quality assurance, and logistics. This shall include support to the development of the OMRSD/OMI's and interface control documents and to the Launch Systems Evaluation Advisory Team (LSEAT) during prelaunch and post-flight evaluations. The extent of this support will be as defined and approved in our contract with the NASA/MSFC LRB Project Office. Specific areas in which we will provide constructive support to the STS systems engineering and integration activities are:

(1) Mission Requirements and Integration

-Ascent performance post-flight reconstruction.

-Ascent Performance Data Book maintenance and update.

-EO trajectory conditions and abort modes.

(2) Aerodynamics

-Aero Data Book.

-Ascent vehicle aero characteristics.

-Aero uncertainties.

-Manufacturing tolerance effects on performance.

-Wind tunnel test planning and requirements definition.

(3) Thermal Analysis

-Element aeroheating math models.

-Plume effects.

-Thermal Interface Design Data Book (TIDDB) maintenance and update.

(4) IGN&C

-Six DOF simulations.

-LRB separation modeling.

-Engine performance parameters and dispersions.

-LRB aeroelastic effects and dynamic responses.

(4) Integrated Avionics

-SAIL test requirements.

-Integrated avionics configuration compatibility verification.

-LPS software requirements.

(5) Structural Loads and Dynamics Analysis

-Math modeling; modal data development; external loads; shock, vibration and acoustic environments; pogo; flutter and buffet; ignition overpressure.

-Monitor element dynamic analyses.

(6) Integrated Propulsion

-Propellant loading math model.

-Static test firing plans, procedures, profiles.

- Pressurization system.

(7) SAIL Testing

-Interfaces with MMES and LPS.

-SAIL Flight System Test and Implementation Plan.

-SAIL Level II ICD's.

(8) NSTS Operations Maintenance and Requirements Specification Documents (OMRSD)

-Support systems analyses for accomplishing maintenance and update of LRB Assembly and Checkout OMRSD and LRB Prelaunch OMRSD

-Assure the Operations Maintenance Plan (OMP)/Operations Maintenance Instructions (OMI) are compatible with the OMRSD.

-Assure OMRSD includes verification of LRB interfaces; end-to-end subsystems performance; and mission requirements.

(9) Support the maintenance and update of the following systems and element ICDs:

• Interface Control Documents - Level II

-ICD-2-12001	Orbiter Vehicle/External Tank
-ICD-2-14001	Orbiter Vehicle/Liquid Rocket Booster (LRB)
-ICD-2-24001	ET/LRB
-ICD-2-00001	Shuttle Vehicle Mold Lines and Protuberances.
-ICD-2-0A001	Shuttle System VAB and MLP.
-ICD-2-0A002	Shuttle System/Launch Pad and MLP
-ICD-2-0A003	Flight Vehicle/LPS Computational System Interface.
-ICD-2-4A001	LRB/Receiving and Processing Station
-ICD-2-4A002	LRB Retrieval Station (if required)

• ICD's - LRB Level III

-ICD-3-44001	LRB/Forward Skirt
-ICD-3-44002	LRB/Systems Tunnel
-ICD-3-44003	LRB/Aft Skirt and TVC
-ICD-3-44004	LRB/ET Attach Ring
-ICD-3-44006	Decelerator Subsystem/LRB Forward Skirt and Nose Assembly (if required)
-ICD-3-44007	BSM/LRB
-Dwg 10A00332	LRB Mold Lines and Protuberances.

4
PRODUCT ASSURANCE

4.1 APPROACH

The product assurance program for the LRB will be tailored to meet the LRB requirements using the existing General Dynamics Space Systems Division (GDSS) Systems Effectiveness Program Plan (SEPP) as a base. The SEPP conforms to the requirements of NHB 5300.4 (1D-2) and the LRB program will continue to satisfy the requirements set forth therein. The LRB product assurance program shall encompass the disciplines of system safety, reliability, maintainability, producibility, and quality assurance.

The Product Assurance Manager will report directly to the LRB Program Manager and also to the Corporate Vice-President for Assurance. He shall be responsible for all product assurance activities for both the in-house LRB program and all subcontractors except for system safety. The System Safety Manager will also report directly to the Program Manager in order to assure independent management and assessment of system safety issues. The Product Assurance and System Safety Managers will be the sole points of contact within the prime contractor for all customer relations in the area of product assurance.

While the SEPP shall represent the guiding document for all product assurance activities, a separate System Safety Plan will also be prepared. All plans will specify the administrative means and techniques for satisfying the requirements of NHB 5300.4 (1D-2). These plans will cover all aspects of the LRB program: design, development, procurement, production, test, and operations.

The LRB product assurance program will include a motivational program as an integral part of the activities of every discipline, to promote awareness among all program participants of the importance of their individual efforts to Space Shuttle mission success. This motivational program will include goal setting, error cause identification and removal, recognition for superior performance, indoctrination for supervisory personnel, and distribution of motivational information.

4.2 SYSTEM SAFETY

The System Safety Manager will report directly to the Program Manager and shall be responsible for preparation and implementation of the LRB System Safety Plan. The safety plan will establish the management structure and techniques for meeting the requirements of NHB 5300.4 (1D-2), Chapter 2. Existing GDSS plans reflecting experience on Atlas-Centaur, Shuttle-Centaur, and Titan-Centaur will be used as a reference. The plan will apply across the total LRB Program, including system design and development, test operations, flight operations, and subcontractor safety management.

Major elements of the system safety plan will include definition of organization and responsibilities, safety design criteria and trades (including software), hazard analysis, control and verification, test requirements, training and certification, documentation, and audit. Integration with other technical disciplines and with interagency working groups and the phased safety reviews of the NSTS Program will be defined. The plan will list the control documents and procedures.

4.2.1 PRELIMINARY HAZARD ANALYSIS

A preliminary hazard analysis is being conducted. The hazard analysis will utilize the hazardous top level event approach. In this approach, top level events are defined which incorporate the gamut of hazardous conditions which could potentially cause injury or death to personnel, damage to or loss of equipment, or other accidents. These hazardous top level events have been defined for the Liquid Rocket Booster and are depicted in Table 4-1.

Table 4-1
Hazardous Top Level Events

HTE 001 - PERSONNEL INJURY DURING PROCESSING OR FLIGHT

Hazard Description: Personnel injury results in physical injury or detriment to health of personnel.

HTE 002 - COLLISION/IMPACT DURING HANDLING/TRANSPORTATION

Hazard Description: Fire/explosion could result in damage to system, Aerospace Ground Equipment, facility hardware, facility, or loss of vehicle.

HTE 003 - FIRE/EXPLOSION (NON-ORDNANCE)

Hazard Description: Fire/explosion could result in damage to system, Aerospace Ground Equipment, facility hardware, facility, or loss of vehicle.

HTE 004 - RUPTURE/IMPLOSION OF PRESSURANT/PROPELLANT SYSTEM COMPONENTS

Hazard Description: Rupture/implosion of pressurized containers, vessels, or components could result in high energy release and damage to system, facility hardware or vehicle and mission loss/delay.

HTE 005 - STRUCTURAL/MECHANICAL FAILURE UNDER LOAD

Hazard Description: Structural/mechanical failure under load could result in damage to system, vehicle, facility, facility hardware and mission loss/delay.

Table 4-1
Hazardous Top Level Events (Cont'd)

HTE 006 -
INADVERTENT ORDNANCE INITIATION

Hazard Description: Inadvertent ordnance initiation results in unexpected release of energy which could damage system, vehicle, and/or facilities.

HTE 007 -
PREMATURE/INADVERTENT ACTIVATION OR FAILURE OF FLIGHT TERMINATION SYSTEM

Hazard Description: Premature/inadvertent activation of the FTS could result in loss of the vehicle and/or facilities. Failure of the FTS to activate upon command could result in injury to the public or damage to property.

HTE 008 -
VEHICLE POSITION REQUIRES DESTRUCT

Hazard Description: Vehicle position requiring destruct could result in loss of vehicle and mission failure.

HTE 009 -
ELEMENT RECONTACT DURING FLIGHT

Hazard Description: Element recontact during flight could result in structural damage and/or loss of system, vehicle, or mission.

HTE 010 -
IMPROPER BOOSTER REENTRY/IMPACT

Hazard Description: Improper booster reentry/impact could result in inability to recover liquid rocket boosters, damage to the boosters precluding refurbishment, or impact of boosters in an area presenting a hazard to the public.

Potential hazard causes which can lead to a hazardous top level event have been categorized as shown in Table 4-2. The hazard analysis will be organized by hazardous top level event. Within each top level event, hazard causes will be defined by subsystem and subsystem elements as well as by cause category.

Table 4-2
Cause Categories

S/M	Structural/Mechanical
MAT	Material
CON	Contamination/Corrosion
ELE	Electrical
CHE	Chemical
ENV	Environmental
PRS	Pressures
PYR	Pyrotechnics
PRO	Propulsion
RAD	Radiation
EMI	Electromagnetic Interference
T/A	Toxicant/Asphyxiant
THE	Thermal
IMP	Impact/Collision
OPE	Operator Error
PRE	Procedure Error
SWE	Software Error

Causes which can lead to more than one hazardous top level event will normally be reported under the event which would occur first.

At least one control will be established for each hazard cause. Controls may either be design or procedural. The optimum control is a design feature that ensures the inherent safety of the vehicle and crew, associated ground support equipment, facilities, and personnel to the maximum extent possible. Particular attention will be given to primary system design to assure that any gradual deterioration of a function will permit detection of the hazardous condition in time to effect control counteractions. If risks cannot be totally controlled by design action, they can be controlled by safe devices such as mechanical barriers or inhibiting mechanisms; by protective systems such as fire extinguishing systems, radiation shielding, or personnel protective equipment; or by warning devices which are used in conjunction with proper emergency plans and procedures. Finally, when none of the foregoing actions are possible or applicable, procedural control will be utilized to limit the initiation of a hazardous sequence of events.

Each hazard control will be verified. This verification will be documented in the hazard analysis. Verification can be by inspection, analysis, or test. For an item to be closed, the verification must be complete.

Prior to processing and first launch of the liquid rocket boosters, as many hazard items as possible will be closed. For any item remaining open, the risk of proceeding will be assessed. This risk must be found to be acceptable by both contractor and government program management.

The system safety organization has been actively involved in the trade studies leading to the proposed liquid rocket booster concepts. The proposed concepts have been reviewed from a safety viewpoint. All of the approaches involve state of the art technology with no associated high risk safety factors. Detailed risk assessment of the proposed concepts will be continued through concept development and the hazard analysis process. Two areas, propellant management and engine health verification prior to liftoff, require special attention. Three of the proposed concepts use propellants that are not currently found on the STS launch complexes. Two concepts utilize RP-1 and one concept utilizes liquid methane (CH_4). Verification of engine health prior to liftoff is a primary safety issue and is envisioned to be accomplished in a manner similar to that currently used for the SSME's. System safety will assess the procedures to be used as the engine ignition sequence and thrust buildup characteristics are better defined.

4.2.2 SYSTEM SAFETY CRITERIA AND REQUIREMENTS

Safety requirements for LRB planning, design, manufacturing, testing and operations will be developed and documented as an integral part of the hazard analysis and risk assessment. System safety will perform a risk comparison during trade studies to include areas such as fail operational/fail safe combinations; equipment and functional redundancies, and operational considerations. All Category I and II failure modes identified in the Failure Mode and Effects Analysis will be incorporated in the hazard analysis where system safety will define controls and verifications thus providing a closed loop tracking system for these failure modes. System safety will place special attention on liquid rocket booster interfaces with the STS orbiter with emphasis on all aspects of crew and vehicle operations and procedures. Stress safety factors will be totally evaluated in terms of both test and operational requirements. Safety consideration will be given to all aspects of integrated facility, ground support equipment and vehicle operations. System safety will coordinate activities with industrial safety and test operations safety to ensure an effective and integrated safety effort. The application of hazard control will consider severity, frequency and cost factors in terms of impact potential, design options, reaction time and procedural controls.

4.2.3 TECHNICHAL RISK MANAGEMENT SUMMARY

A composite listing of all identified technical risks and hazards with associated control actions is being developed in conjunction with the refining of design for the proposed concepts. As no high technology development has been identified for the liquid rocket boosters, technical risk appears to be managable. Primary safety related technical issues will evolve around those concerns associated with interface of the liquid rocket boosters with the Shuttle stack, interfaces and modifications required at the Shuttle launch complexes, and operational interfaces required to minimize risk to the flight crew. To ensure all technical risks are properly identified, system safety personnel are totally involved in trade studies, the design process and the management process for the liquid rocket booster program. In addition, system safety reviews technical analyses including FMEA's, stress analysis, thermal analysis and dynamic analysis and incorporates these analyses into the overall hazard analysis and technical risk assessment.

4.3 RELIABILITY

The Reliability Engineering function will report to the Systems Engineering Director and will be responsible for preparation and implementation of the LRB

Reliability Plan. The reliability plan will establish the means for meeting the requirements of NHB 5300.4 (1D-2), Chapter 3. GDSS experience on Atlas-Centaur, Shuttle-Centaur, and Titan-Centaur will be drawn upon as applicable in the preparation and execution of reliability plans. The plan will apply across the total LRB Program including subcontractors.

Reliability engineering shall be an integral part of the design and development process and will include the evaluation of hardware reliability through analysis, review, and assessment. Reliability tasks will emphasize the qualitative and quantitative evaluation of hardware and operations including ground support equipment and launch vehicle interfaces. Supplier control will be defined to assure that the performance of system elements obtained from subcontractors and suppliers meets the reliability requirements of the overall system.

Reliability design criteria will be defined for trade studies and subsystem design. A system will be established for the preparation, maintenance, and control of Failure Modes and Effects Analyses (FMEAs) and Critical Items Lists (CILs). Controls for the selection and use of Electrical, Electronic, and Electromechanical (EEE) and mechanical parts will be a major emphasis of the reliability plan. A system will be defined for the selection, specification, qualification, tracking, problem reporting and corrective action, and control of EEE parts throughout the program.

The reliability plan will include a system for monitoring the hardware certification program and the acceptance testing program to assure that all requirements are adequate to detect manufacturing defects and to assure performance verification.

4.4 MAINTAINABILITY ASSURANCE

The Maintainability function will report to the Systems Engineering Director and shall be responsible for implementation of the LRB Maintainability Plan. The maintainability plan will establish the means for meeting the requirements of NHB 5300.4 (1D-2), Chapter 4. Existing GDSS experience on Atlas-Centaur, Shuttle-Centaur, and Titan-Centaur will be drawn upon as applicable. The plan will apply across the total LRB Program including subcontractors and will identify each maintainability task and describe how each task will be performed.

The maintainability efforts will emphasize maintainability traits associated with accessibility and remove/replace actions that can be anticipated during prelaunch activities. Maintainability design guidelines and checklists will be provided to assist design engineers in evaluating the qualitative maintainability features of the design. Maintainability engineers will monitor design efforts to identify and assist in resolving maintainability issues by participating in design meetings, tradeoff studies, and over-the-board discussions with design engineers.

The maintainability engineers will review design items that may have significant man-machine interfaces to ensure that human engineering principles are properly incorporated.

4.5 QUALITY ASSURANCE

The Quality Assurance organization at GDSS is headed by the Division Vice President, Quality Assurance and will have responsibility for implementation of the LRB Quality Assurance Plan. The current GDSS quality assurance plan meets the requirements of NHB 5300.4 (1D-2), Chapter 5. This operating, in-place system will be modified to incorporate the unique requirements of the LRB Program, and the innovations associated with our preventive quality assurance approach (Section 6.3.4) as they are proven to be effective. The plan will cover the total LRB Program including subcontractors. Features of the plan include:

- Quality planning
- Independent quality organization/reporting
- Drawings/Specifications/Procedures review and approval
- Support for design reviews
- Change control
- Documentation control
- Purchase Order reviews for requirements
- Source inspection
- Major Subcontractor controls
- Receiving inspection
- Metrology controls
- Manufacturing Planning and Tooling review and approval
- Certification of personnel
- Inspection; Configuration verification
- Fabrication control
- Test monitoring
- Measuring and Test Equipment control
- Material Review Control
- Property control
- Process control
- Contamination/cleanliness controls
- Handling/packaging controls
- Stamp controls
- End-item acceptance
- Nonconformance controls
- Corrective action
- Audits (systems requirements compliance and area surveillance)

5
DESIGN AND DEVELOPMENT

5.1 DESIGN APPROACH

The primary objective of the LRB design and development effort will be to generate a safe, reliable, low cost design that can be readily integrated with the STS. Our design approach is to maximize the use of proven design concepts that offer sufficient performance margins. Early tradeoff and sensitivity studies will address performance vs. complexity, weight, cost, and risk. A commonality plan will be completed prior to the Preliminary Requirements Review (PRR).

The design group will be organized for rapid reaction and response to overall program requirements by including staff representatives from all major elements of the LRB Project organization. A staff responsibility will be to focus support for the Systems Integration Review, Ascent Flight Systems Integration Group, and the Interface Working Group for the preparation and coordination of IRDs and ICDs.

Early identification of design requirements will enhance a simple compatible approach. A design goal is to provide an LRB that minimizes the impact on all STS elements. Accomplishing this goal will minimize the amount of testing required to verify the interfaces. Wherever possible, materials will be selected from those already used in the STS program to maximize the use of existing technology and eliminate the need for advanced materials research. Design reviews, such as the PRR, PDR, and CDR, will be scheduled at strategic points in the design and development process to assure a coordinated program that satisfies all functional requirements.

5.2 FLIGHT HARDWARE

While proven technologies will be used during design and development of the LRB, the foremost program concern will be to improve Shuttle safety by eliminating failure modes, reducing criticality of failure, and providing additional abort modes and approaches. Enhancement of Shuttle performance and relaxation of Shuttle operating constraints are other key requirements that will be used as a basis for determining and implementing the preferred design and development approach for the LRB.

5.2.1 STRUCTURES

In the design and development of LRB structures, we will strive to ensure downstream producibility by recognizing the manufacturing implications of our design concepts. Aluminum will probably be the basic structural material used in our LRB structures. The properties and use of this material are well established, minimizing the cost and risk of materials development and fabrication. The tanks are designed as monocoque and semi-monocoque vessels that will support the STS "stack" in the vented condition freestanding, during flight readiness firings, and during liftoff transients.

While the use of aluminum will facilitate materials development and fabrication, some forming development may be required, due to the thicker skin requirements (up to one inch) of the pressure-fed system. The juncture of the tank dome, cylinder, and adapter flange will require development efforts to ascertain the strength impact or subsequent treatment, if required.

As part of the LRB structure and tankage development, significant analysis and testing will be required. To reduce costs, we recommend using analysis, computer simulation, and reduced scale model test verification in lieu of full scale testing whenever possible (see Section 7). For example, a significant amount of structural analysis will be needed to determine pre-ignition, launch, and flight loads into the various elements of the STS stack. Many of these analyses can be performed using tools already in widespread use at GDSS, such as NASTRAN. However, a full scale structural item will be required to verify fabrication and for pressure proof tests. Propellant flow tests and sensor verification will also be required. These tests can be performed at the contractor's facility or at MSFC.

5.2.2 SEPARATION SYSTEM

Due to its commonality with the SRB separation system, the LRB separation system should require relatively modest development effort. However, as both the pump fed and pressure-fed LRB concepts are longer than the SRBs, extensive separation dynamics investigation will be required to assure adequate and clean separation under all conditions, including abort modes. Separation dynamics evaluation should be conducted by mathematical simulations supported by subscale model wind tunnel testing. Math modeling and analyses can be performed by the contractor. Wind tunnel testing and mechanism separation verification are best conducted at government facilities such as those located at MSFC.

5.2.3 THERMAL CONTROL

The LRB will utilize passive thermal protection and control, consisting of various types of insulating materials. If liquid hydrogen is used, there will be an additional requirement for active thermal control systems to vent the LH2 tanks. The three critical areas of the LRB that will require passive thermal protection are:

a) protection of the nose cone and aft skirt from ascent heating

b) prevention of ice accumulation on cryogenic tanks and feed lines

c) protection of the pressurization tank from excessive heating.

Thermal protection for ascent heating can be achieved by deploying an ablative insulating material on the nose cone and aft skirt in a manner similar to that currently used for the ET. Analyses and trades early in the design and development phase must be performed to determine whether this represents the best approach for the LRB. The LO2 tank can be insulated utilizing a similar technique. The pressurization tank will probably also require the use of insulation. If it is determined that existing thermal protection techniques can be applied to the LRB, little new development will be required. An applications demonstration and verification can be made on a flow-through full scale test article.

5.2.4 PROPULSION

The pump-fed and pressure-fed LRB concepts both require new booster engines. Development of new man-rated engine systems represents a significant design and development task; in the case of the LRB, propulsion system development will represent a large share of the overall DDT&E effort.

5.2.4.1 Engines

Efficiency requirements for pump-fed LRB engines can be relaxed, since additional propellant in the LRB can be substituted for engine inefficiency. This will allow the application of current pump-fed rocket engine technology. Engine chamber pressure should be optimized to permit the use of a larger, lower speed turbo-pump system that minimizes concerns regarding bearings, shafts, and seals. The planned oxidizer-cooled gas generator engine cycle is a well established design concept. The development effort for this new engine would be much less than that associated with complex, highly efficient engines such as the SSME. Initial engine development should be at the engine contractror's facility. Pressure-fed engine tests will be conducted at NASA/MSFC. Cluster firing tests can be performed at MSFC or NSTL.

The pressure-fed engine development philosophy should be the same as for the pump fed; i.e., to emphasize propellant energy rather than efficiency to reduce complexity. While pressure-fed engines are generally simpler than pump-fed engines, the size of the pressure-fed engines that will be required for the LRB introduces several complexities. As is the case with pump-fed engines, full scale development, fabrication, and test firing of pressure-fed engines can be conducted at the engine contractor's facility, with cluster firing tests performed at MSFC or NSTL.

5.2.4.2 Engine Feed System

The propellant feed system must be designed to minimize losses and to eliminate inactions such as geysering and POGO. Sump screens will be needed at each inlet from the tanks. For the pump-fed engine concept, fuel lines are routed with the bellows to allow for head-in gimbaling. For the pressure-fed engine, high pressure gimballing lines, including a LO2 feed line through the center of the RP1 tank, may be required. These would pose new development challenges, although relatively little new development will be required for the pump-fed systems. Layout, flow characterizations and evaluations can be accomplished utilizing the full scale flow test LRB assembly.

5.2.4.3 Pressurization

Pressurization systems for both pump-fed and pressure-fed LRB concepts currently utilize helium. The pump-fed version can utilize a 50 psia system similar to that used on existing LO2/RP-1 launch vehicles. It requires almost no development, with the exception of a demonstration using the full scale LRB flow test article. The pressure-fed LRB, which requires larger volume propellant vessels maintained at much greater pressure, represents a greater challenge in the pressurization system development. The proposed Tridyne system would entail a significant design and development effort to assure applicability and safety. This activity should be done at the contractor's facility. Final testing and demonstration would be with the full LRB engine demonstration.

5.2.5 ELECTRICAL POWER

The LRB will have a self-contained power system independent of that used by the Orbiter. Prior to lift-off, ground power facilities at the launch pad can be used for all LRB functions. After lift-off and umbilical separation, on-board power will be provided by an autonomous source such as batteries. Back-up batteries will be needed for mission-critical fuctions such as engine shutdown and LRB separation. The batteries and power distribution and management system will maximize the use of established technologies to minimize the design and development effort. A functional brassboard arrangement will be constructed to demonstrate and verify operations for all mission conditions. Full assembly verification shall be performed utilizing the full-up, full scale LRB systems test, and should be conducted at the NSTL.

5.2.6 AVIONICS

LRB commands and telemetry with the Orbiter will be through the OIU. The Orbiter to LRB input/output functions and interfaces will be similar to those utilized by the SRB, reducing development time and cost. Other LRB avionics functions will be unique, requiring development and verification and validation of programmed software. The avionics system design and development will be sequential simulations. Multi-element computer simulation of the planned avionics architecture will be developed initially. Brassboards of the elements will then be connected for design verification; followed by element production model items substitution. First production elements will be verified by hardwire hook-up to a computer-stimulated OIU for all mission parameters. A complete avionics system is to be included in the full-up, full scale LRB propellant flow tests and cluster engine firings. All computer and element simulations are to be done at the contractor's facility. Installation, checkout, and demonstration on the full-up, full scale LRB will be at the NSTL.

5.2.7 ORBITER AND EXTERNAL TANK

The increased length of the LRB relative to the SRB may introduce increased loads into the ET. Identification of design impacts and load verification will require wind tunnel testing and detailed loads analyses. These tests should be conducted with a scaled model at an existing government facility such as MSFC or AEDC. If the loads into the ET fittings exceed design allowances, ET design modifications will be required. The full-up, full scale LRB should be attached to an ET, as a structural simulator, for cluster firing tests to evaluate dynamic responses. To avoid the high cost associated with development of a full scale mock-up, an electronic mock-up should be used to verify electrical interfaces between the LRB and ET.

5.3 GROUND SUPPORT EQUIPMENT (GSE)

5.3.1 FACTORY

Many LRB elements will be designed, developed, and manufactured by subcontractors who specialize in those specific technologies. Remaining LRB elements and final assembly will be performed at a plant designed and built by the prime contractor. The assembly plant will be designed to receive, inspect, and store all LRB elements received from subcontractors, as well as to support fabrication and check-out of the LRB. The final assembly facility can be located anywhere with convenient access to the launch site, although verification and transportation requirements can be reduced if the plant is located in the local KSC area.

5.3.2 TESTING

Initial component testing will be the responsibility of the LRB suppliers. Development testing of the flight hardware will be performed at a variety of locations, including the final assembly plant, NSTL, and MSFC. During the development program a full size LRB test article must be provided for prototype proof and vibration testing, which can be performed at MSFC test facilities. A more detailed description of LRB verification requirements and plans is contained in Section 7 of this document.

5.3.3 TRANSPORTATION

Commercial transportation modes can be used throughout the development and production of either the pump-fed or pressure-fed LRB concepts. The pump-fed concept component dimensions are such they all can be shipped via truck or rail to the prime contractor's assembly facility. For the pressure-fed LRB, rolled formed tank segments will have to be shipped by inland water ways because the LRB diameter is likely to exceed the 14-foot height (above road bed) and width limits of the interstate highway system. Shipment of the assembled LRB from the assembly plant, to the NSTL for testing, and to KSC for launch will be via inland waterways or along the coast. Barges of the type constructed for Saturn stages or the ET are applicable for the assembled LRB. If LRB final assembly is performed in the vicinity of KSC (see Sections

6 and 8), transportation requirements will be greatly simplified. In any case, no major new transportation development is envisioned for the LRB program.

5.3.4 LAUNCH SITE

New ground support handling equipment will be required for the LRB. If the LRB is shipped to the launch site from a distant location, it will be delivered in the horizontal mode. New equipment will have to be designed for use at KSC to rotate the LRB to the vertical position for stacking in the VAB. All of the LRB launch site ground support and handling equipment will be designed and developed by KSC in conjunction with the LRB contractor. This GSE will be verified with the LRB check-out unit.

While all LRB avionics and electrical circuits will be checked via the ATE at the assembly site prior to shipment, a duplicate ATE will be sent to KSC during development to interface with the LPS evaluator to verify compatibility. This ATE GSE will be designed and developed as part of the avionics development task discussed in Section 5.2.6. The LPS evaluator modification development will be conducted by KSC in conjunction with the LRB contractor. Facilities must also be developed at the launch site for installation of batteries and pyrotechnic devices on the LRB. A more detailed discussion of KSC requirements and facilities is contained in Section 8 of this document.

5.4 SOFTWARE

5.4.1 SCHEDULES AND PLANS

Four types of software will be required for the LRB: software required for internal LRB operations, software needed for ATE operations, software to simulate the Orbiter side of the OIU during testing, and LRB-ET-Orbiter software. The development plan for LRB and ATE software is to conduct this effort in parallel with avionics development, first creating software for simulations, followed by development of software for the development test programs, and ultimately the development of software to support LRB operations.

5.4.2 FLIGHT SYSTEMS

The software to support LRB flight will be developed in three phases: initial, demonstration, and final. All software will be tested to assure adequate responses for all mission aspects. The primary focus of the development of LRB flight systems software will be to assure LRB safety, reliability, and ability to meet mission requirements.

5.4.3 GROUND SYSTEMS

A variety of software programs will be required for the many ground systems that will be needed to support evaluation activities. At the assembly plant, software programs will have to be developed or modified for the ATE, automated fabrication equipment, and quality assurance operations. At the launch site, software will have to be modified or developed to support numerous computer-controlled evaluations. These include receiving, post-stock and pre-launch to lift-off control, and evaluation software for the LPS. It is expected that LPS software will be developed and verified by KSC with requirements provided by the LRB prime contractor.

5.5 ADVANCED/NEW TECHNOLOGY DEVELOPMENTS

Since the philosophy of the LRB design and development program is to reduce cost and risk by maximizing the use of existing technology, there will be relatively little development of new technologies. Many of the new technologies that are developed will relate to the development of LRB engines. The LRB tanks and structures employ established design and fabrication techniques with aluminum. To reduce weight and size it would be desirable to utilize a lighter aluminum/lithium alloy. This would entail some advanced manufacturing technology development. As advanced development work is continuing on Al/Li, the degree of additional development efforts for LRB applications will depend on the status at the time of LRB acquisition commitment.

6
MANUFACTURING

6.1 APPROACH

The manufacturing approach for LRB requires total prime contractor commitment to support the program from concept development to test and checkout prior to final shipment. The following sections further define the methodology and support functions of manufacturing and their relationships to the program.

6.1.1 PRODUCIBILITY

Efficient manufacturing begins with the cooperative efforts of design and producibility engineers. Producibility engineers will actively participate in all trade studies, engineering reviews, and concept reviews to assure that manufacturing considerations are incorporated into the design. Producibility engineers will report to the LRB Program Manager as well as to their own functional manager. In this environment, they will not only be kept abreast of the program commitments, but can also maintain continuity with the new manufacturing technologies being developed on other programs.

The producibility engineer will be colocated with the design engineers and will be an integral contributor to the design process. The prime objective of the producibility engineer will be to provide the design staff with the most economical methods to manufacture concepts that can be accomplished within the production environment. The producibility of a new vehicle is largely driven by the methods used to develop a specific design. The LRB design will therefore reflect the best capabilities of manufacturing to reduce cost and risk. Advancements in the manufacturing process will be assessed to identify ways to reduce cost and risks. The basic design concepts will be coordinated with the producibility engineer. Various production approaches shall be examined, and those that best accomplish the intent of the design while meeting the criteria for a production environment will be selected.

By coordinating the designs at the concept level and providing manufacturing input, the producibility engineer effectively begins the process of establishing the preliminary manufacturing plan.

6.1.2 MAKE/BUY PHILOSOPHY

The preliminary manufacturing approach for the LRB is to provide in-house assembly, test, and checkout of the vehicle, and to procure from subcontractors the detail components and sub-assemblies that go into those assemblies. With this approach we will best utilize each vendor for their expertise and eliminate expenses normally accrued through internal facilitization, training, tooling, personnel, and maintenance. The manufacture of certain sub-assemblies, such as the weld assemblies of the fuel and oxidizer tanks, will remain in-house to take advantage of General Dynamics' proven capabilities in these critical processes. As the concepts and designs for the LRB evolve, the Make/Buy policy will be refined.

6.2 MANUFACTURING FACILITIES

The manufacturing facilities will support final assembly and checkout of the LRB prior to shipment to the launch facility. The location of the final assembly facility has not yet been determined. Locating the final assembly facility at or near the launch site would eliminate costly and potentially hazardous transportation problems. If the final assembly facility is not located at the launch site, certain checkout procedures may need to be performed twice, once at the factory and again at KSC. Depending on the distance between the factory and launch site, this could require costly duplication of manpower. Conversely, lower manufacturing costs might be achieved if the factory is located away from the KSC area.

The level of automation to be utilized within the facility will be determined in future phases of the program. To minimize program costs and risks, the automation guidelines will be guided by both cost and reliability considerations. Due to low projected launch rates (6–14/year), automation may not be as cost-effective in certain manufacturing applications as it would be for a higher production program. However, with sufficient commonality of components, benefits of automation could be increased. Automating certain parts of the production process might also help improve quality by increasing consistency, thus reducing program risk and the cost of rework.

6.3 MANUFACTURING CONTROL

Effective control of the manufacturing process consists of four major elements: development of sound manufacturing methods, effective planning, tooling, and quality control. These important program considerations are summarized below.

6.3.1 METHODS

The basic manufacturing plan will be established during the Preliminary Design phase by producibility function, and will be constantly updated as the design evolves. The manufacturing plan will also grow in detail to support manufacturing, estimating, and scheduling. Tooling, process planning and manpower loading of the program will be derived from this plan.

A Manufacturing Breakdown Structure (MBS) will be developed. The MBS will outline and control the manufacturing process and provide direct traceability to the Work Breakdown Structure (WBS). Figure 6-1 shows an example of an MBS for a liquid oxygen tank design concept.

6.3.2 PLANNING

The planning function will receive their work instructions and direction from the manufacturing plan. This function will be supported by manufacturing engineers who provide formal work instructions to the manufacturing departments. The work instructions will be developed on a computer and controlled electronically to provide paperless planning to the factory floor, and will be coordinated with receiving and production control to allow a smooth flow sequence.

6.3.3 TOOLING

Basic tooling concepts will be developed by the producibility function during the concept development process. These tooling concepts are an integral part of the manufacturing process and the development of capabilities to support these processes. Figure 6-2 shows a tooling concept for a radial weld fixture that may be selected for welding tank bulkheads.

Figure 6-3 shows a tooling concept for an adjustable length weld fixture for joining tank constant sections and rings. These tooling concepts lend direct support to the process planning, estimating, scheduling, manpower loading, factory layout development, and the eventual design of the tool.

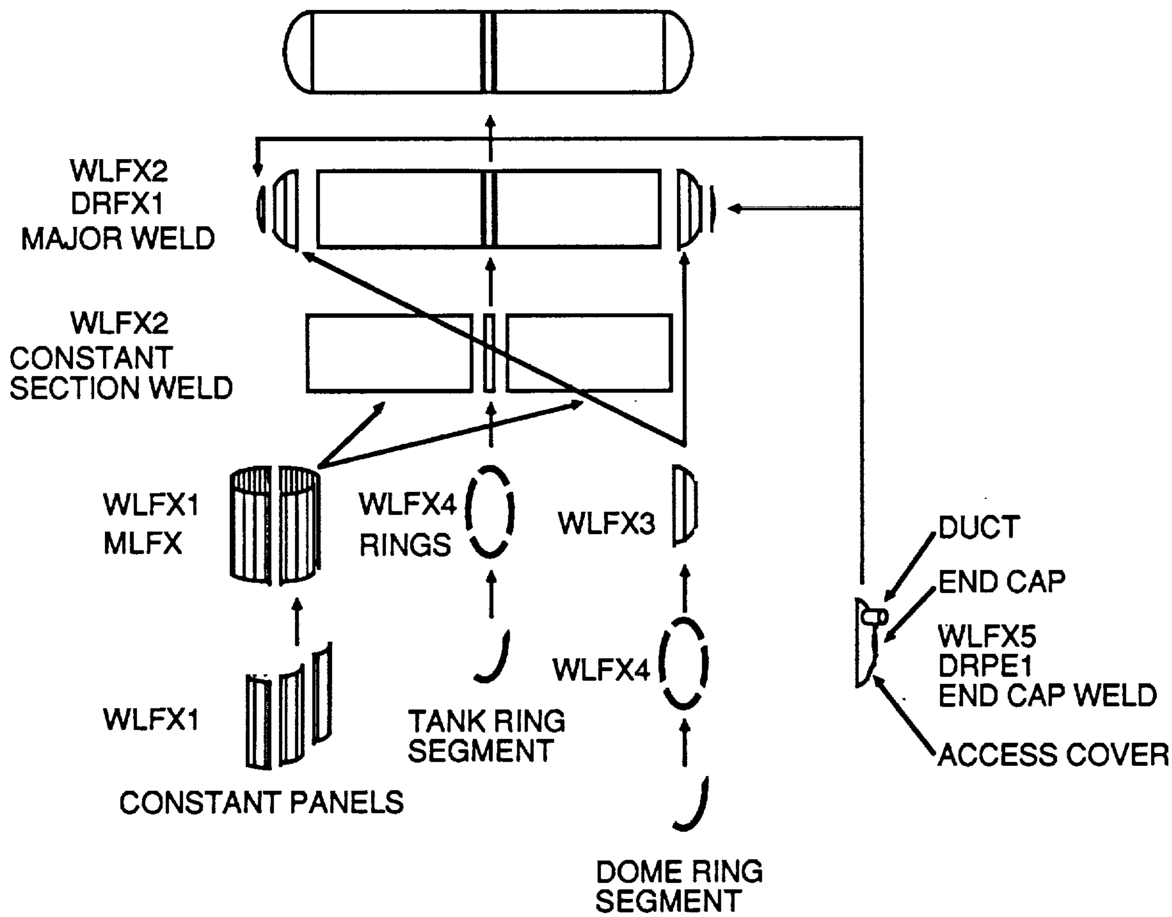


Figure 6-1. Sample manufacturing breakdown structure for LRB liquid oxygen tank.

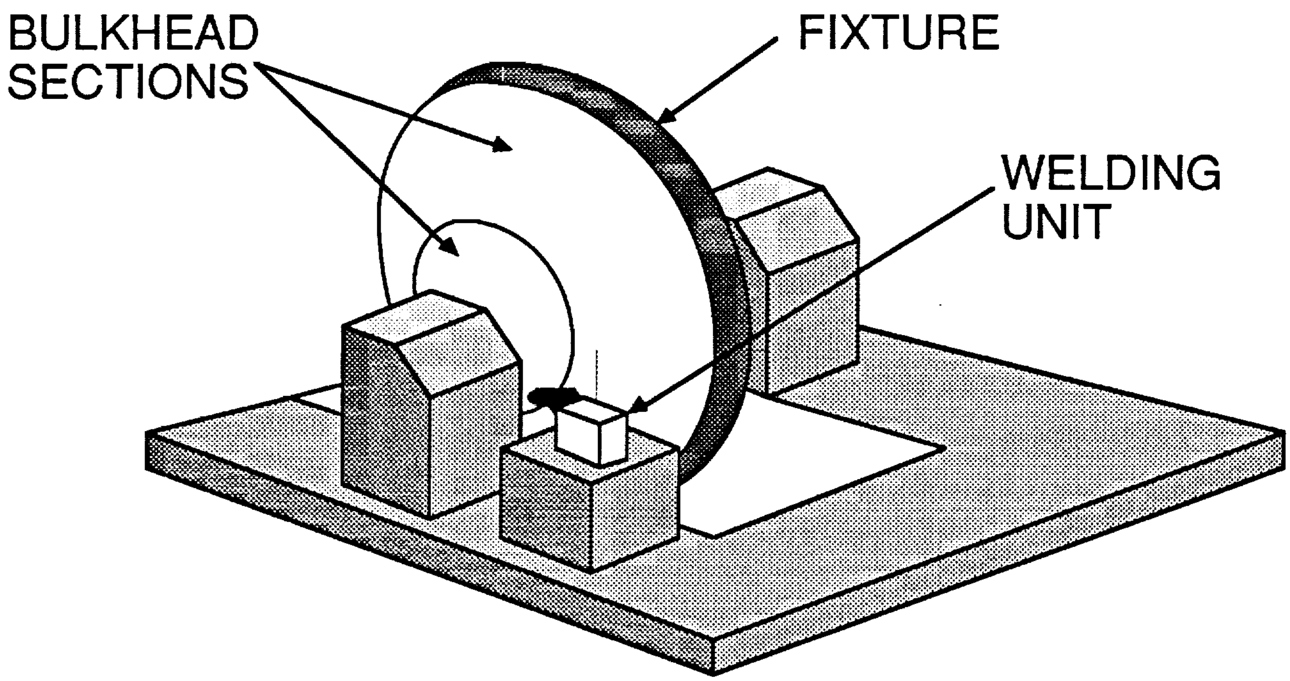


Figure 6-2 . Tank bulkhead weld fixture tooling concept.

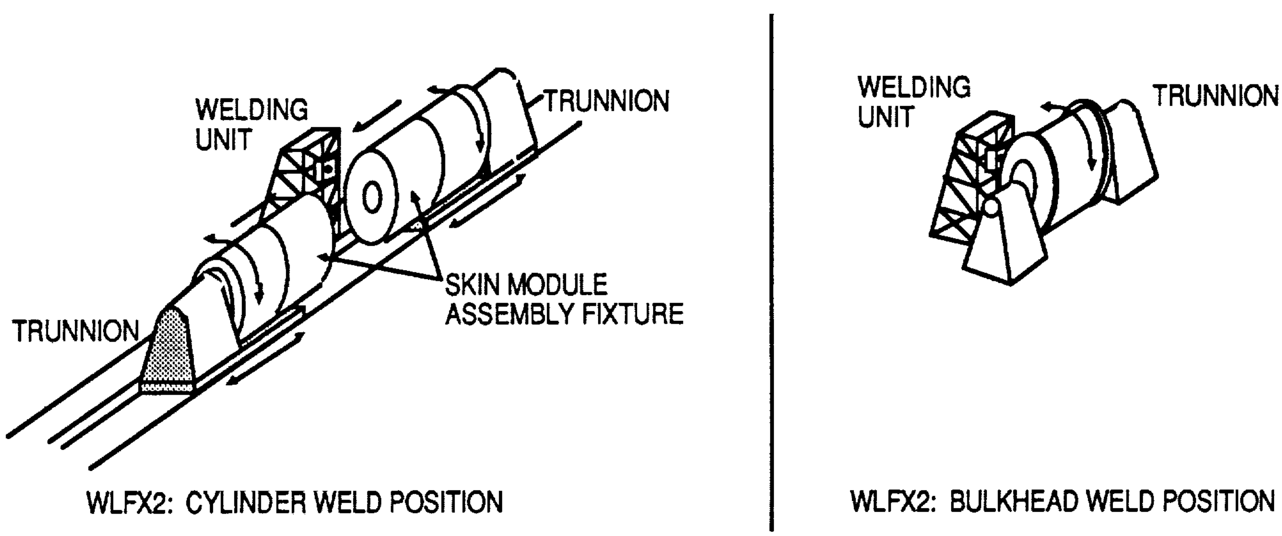


Figure 6-3 . Adjustable trunnion mounted weld fixture concept.

6.3.4 QUALITY

Our quality control is applied early in the design and manufacturing planning process to prevent potential problems before they have a chance to occur. By preventing errors early in the manufacturing process, we can eliminate the scrap and rework normally associated with the traditional quality format. Scanners, probes, and vision systems can be built into the manufacturing process to provide a closed loop network that detects a problem and automatically alters the process to compensate, thus preventing product nonconformances. To meet the goals of the LRB Program, our plan is to use a combination of Total Quality Control (TQC), "Transition From Development To Production" DoD Directive 4245.7 (Willoughby Templates), and Taguchi's approach (see Figure 6-4). These methods represent a cost reduction-oriented approach for product and process optimization, providing an economical means of achieving high quality product. Taguchi's "Systems Design" will assist the design engineer in developing design approaches that meet both cost and quality criteria.

6.4 FLIGHT HARDWARE

6.4.1 STRUCTURES AND MECHANISMS

In the area of structures and mechanisms, there will be many opportunities to utilize state of the art manufacturing methods to reduce costs and to improve quality. The utilization of advanced materials and processes to develop structures such as the bulkheads for both fuel and oxidizer tanks will be explored and developed. Different approaches to fabricating adapters to reduce manufacturing flow times and cost will also be reviewed and alternatives recommended. Reduction of piece parts by combining more than one structural shape into a common extrusion, precision casting, forging, superplastic formed panel or integrally machined part will be studied to reduce the cost and manufacturing risks of product development. Extensive use of Variable Polarity Plasma Arc Welding (VPPAW) and real time radiography will be utilized in the structural build up of many components. Many new processes show promise for application in the manufacture of our LRB design concepts, although some will require further testing and evaluation.

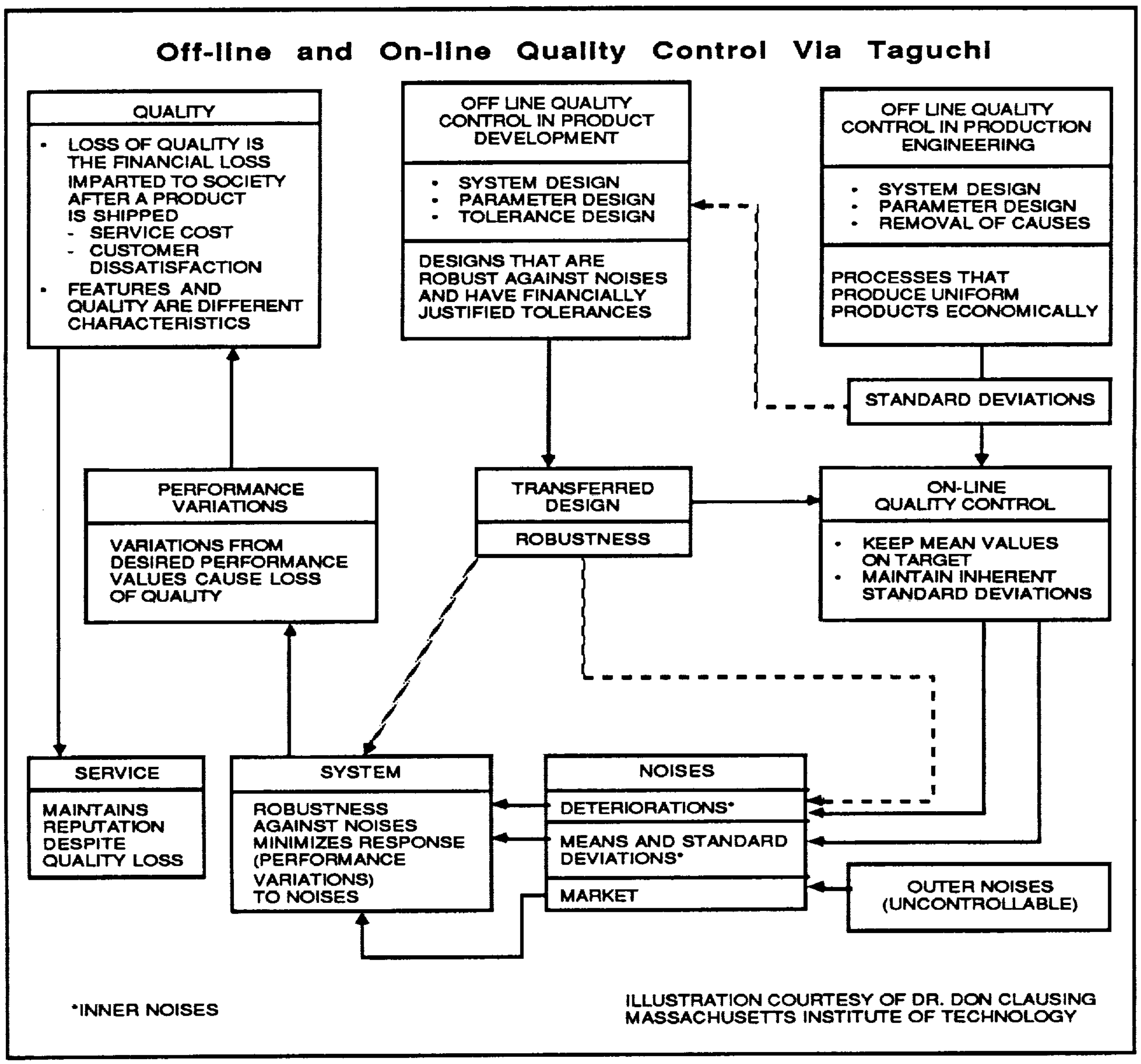


Figure 6-4 Taguchi method of quality control.

Several existing manufacturing technologies will also be utilized to reduce the cost of manufacturing. Processes such as shear forming, spin forming, power feed drilling, automatic riveting, flash welding, and resistance welding will be reviewed and implemented where practical. Some of these technologies will also require up-scaling to be usable on large components.

6.4.2 SEPARATION SYSTEM

Should the booster motors for separation utilize the existing boosters for SRMs, manufacturing concerns are minimal, relating only to the installation procedure. If the booster motors are upscaled, installation and assembly becomes an easier task but test and evaluation hardware will have to be developed for acceptance of the new design.

6.4.3 THERMAL PROTECTION

The application techniques anticipated for applying ablative insulating material to the LRB may be similar to that currently used for the ET. Insulating fuel lines where a spray-on type insulation would not suffice does not pose a problem, nor is any special equipment anticipated for its application. The actual location for application of the thermal protection is dependent on the site selection for the manufacturing facility and its proximity to the launch facility. As further definition is provided to the design, the manufacturing plans will be refined.

6.4.4 MAIN PROPULSION

The vehicle prime contractor shall work closely with the engine contractor to eliminate the complexities of engine installation and ground operations, while still meeting the safety and reliability requirements for the program. Modularity of the engine cluster would facilitate ease of assembly, installation, and ground operations functions, and enable more efficient maintenance. Weld joining of the fuel lines would improve the reliability of these connections and reduce the assembly risks incurred by multiple fastener coupled joints.

6.4.5 AVIONICS

Modular avionics packaging will be manufactured and validated by the individual subcontractors supplying the components to the program. Special tooling is not anticipated for installation and integration of the avionics components into the vehicle.

6.4.6 ELECTRICAL POWER

Electrical power units will be manufactured and validated by the individual subcontractors supplying those units to the program. Special tooling is not anticipated for installation and integration of these units. Wiring harnesses will be fabricated off-site from physical description data down loaded from the CAD design of the vehicle. Harnessing modules will be installed manually or by automated systems within the assembly area.

6.5 ASSEMBLY AND CHECKOUT

Part fabrication and some subassembly manufacturing will be provided by subcontractors that specialize in those specific technologies. All components will be inspected and checked out prior to shipment to the final assembly facility. Each level of assembly and installation will provide in-process inspection and checkout of the assembly and systems build-up. The next higher level of checkout will require only interface checks required to verify that systems are functional. The final test and checkout prior to shipment to the launch facility will provide a total integration checkout verification. A more detailed discussion of LRB verification is contained in Section 7 of this plan.

6.6 GROUND HARDWARE

Assembly and installation material handling and transportation equipment will utilize common equipment with the ground operations function to minimize tooling costs. A detailed description of ground hardware to be used at the launch site is contained in Section 8 of this plan.

7
VERIFICATION

7.1 APPROACH

Our LRB development plan includes establishment of an integrated verification management program to provide efficient and cost-effective control of the verification process. This concept, shown in Figure 7-1, illustrates the fact that verification will be an integral part of the hardware/software design, fabrication, and acceptance process.

Our approach will require and achieve uniform application of requirements across the entire design, manufacturing, and operations process for all LRB components and systems. It will emphasize commonality of data requirements, test requirements, procedures, system models, software support equipment, and functional simulations. It will also emphasize the utilization of built-in test (BIT) in all test activities and will provide the guidelines, criteria, and format for test data, test procedures, test reports, and verification compliance closeout documentation with NASA/MSFC.

The LRB verification process will be implemented in accordance with the LRB *Verification Plan.* This plan will describe philosophy, management, and controls, as well as an overall description of the use of verification methods for the LRB program. It will include all verification activities from the design phase to verification closeout. It will define verification requirements for deliverable hardware, software, support equipment, utilization of major ground test articles, and new or existing test facilities. The LRB Verification Plan will be developed by the prime contractor and shall be subject to the approval of the NASA Marshall Space Flight Center (MSFC).

Prior to initiating development of this plan, we will review the SRB Master

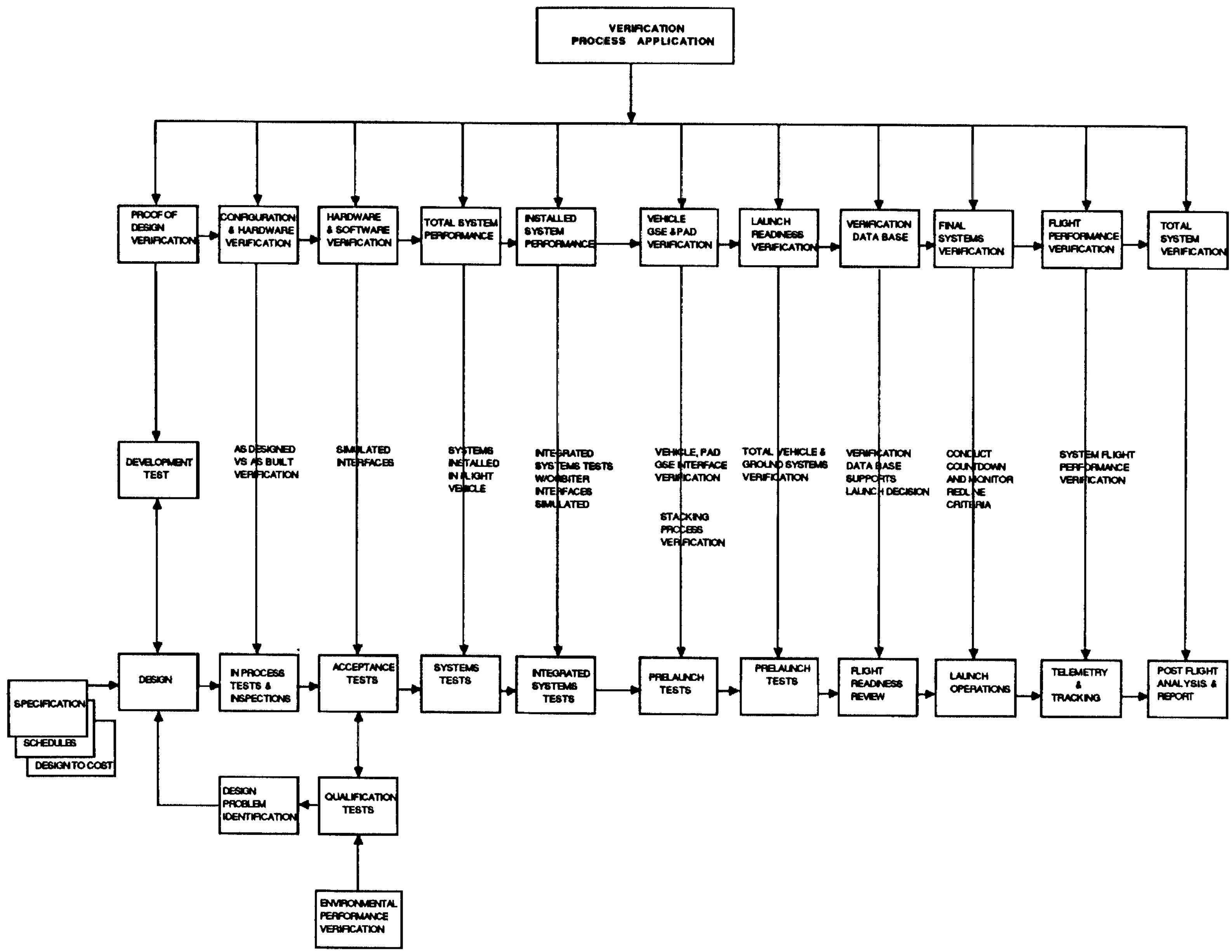


Figure 7-1. Integrated verification management process.

Verification Plan (MVP), using this document as a guide where appropriate. We will incorporate the procedures into the LRB Verification Plan to ensure rigorous documentation and closeout of verification requirements.

Our approach will take into consideration the many facets that drive the verification activities in the development of requirements and the application of methods to meet requirements. Key features of the LRB program that will affect verification requirements and procedures are as follows:

a. The LRB will be used for STS manned missions.

b. The LRB will provide very high thrust levels.

c. The main engine area will be subjected to a very high vibro/acoustic environment.

d. The LRB will perform during a very critical period of flight.

e. Two LRBs will perform in parallel during their normal use.

f. The LRBs are an integral part of the Space Shuttle system.

7.2 VERIFICATION PROCESS

Figure 7-2 depicts the verification process, illustrating that the process includes four major activities: (1) development of verification requirements based upon design requirements, (2) application of methods for accomplishing verification, (3) evaluation of results against established design and performance requirements, and (4) documentation to ensure design knowledge capture. This process will apply to design verification as well as to verification of hardware and software.

The phasing of the test and verification program is presented in Figure 7-3. The heavy outline shows the scope of the verification process, while the inner dashed line indicates the activities that are associated with the certification process. Certification

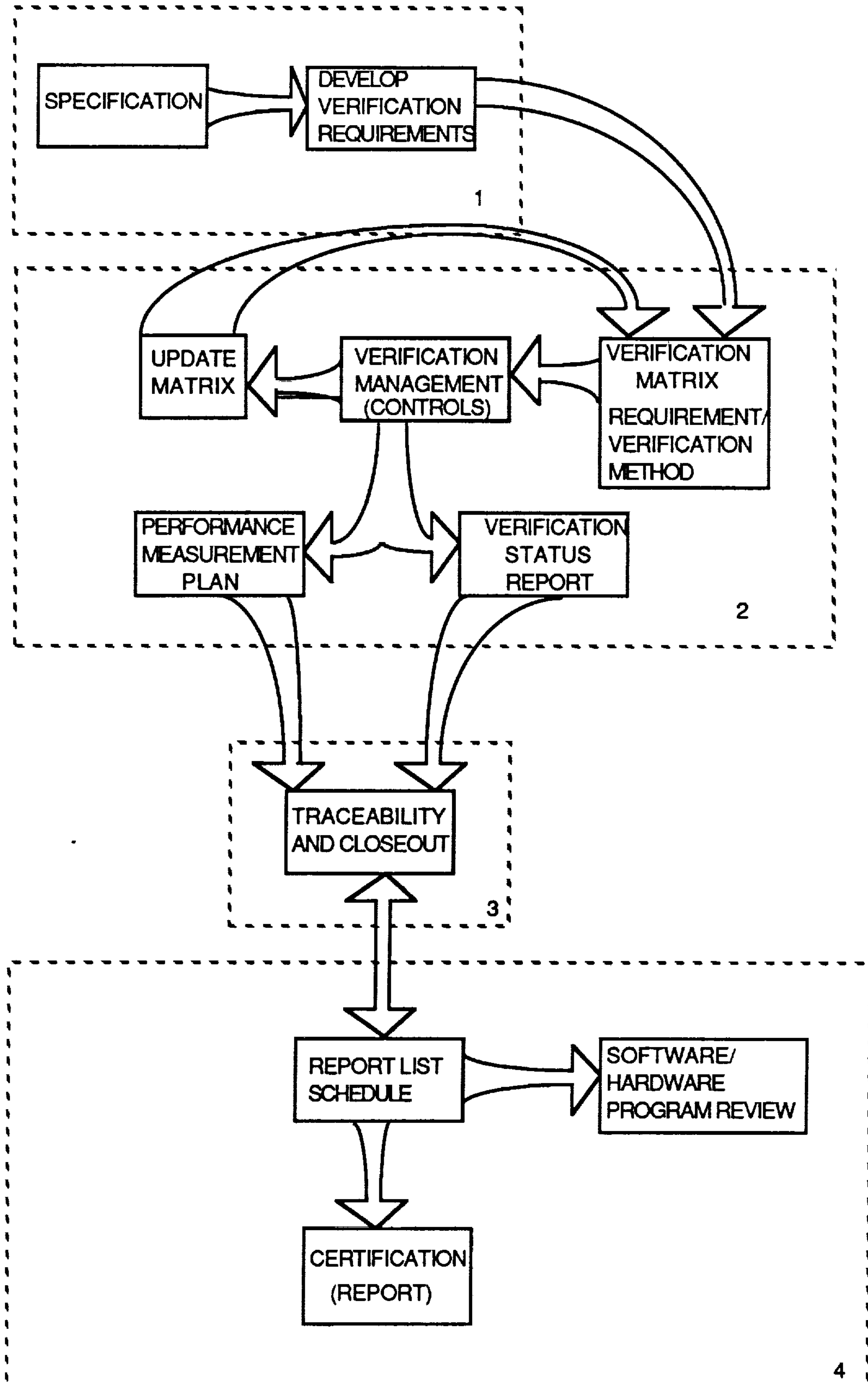


Figure 7-2. Four major elements of the verification process.

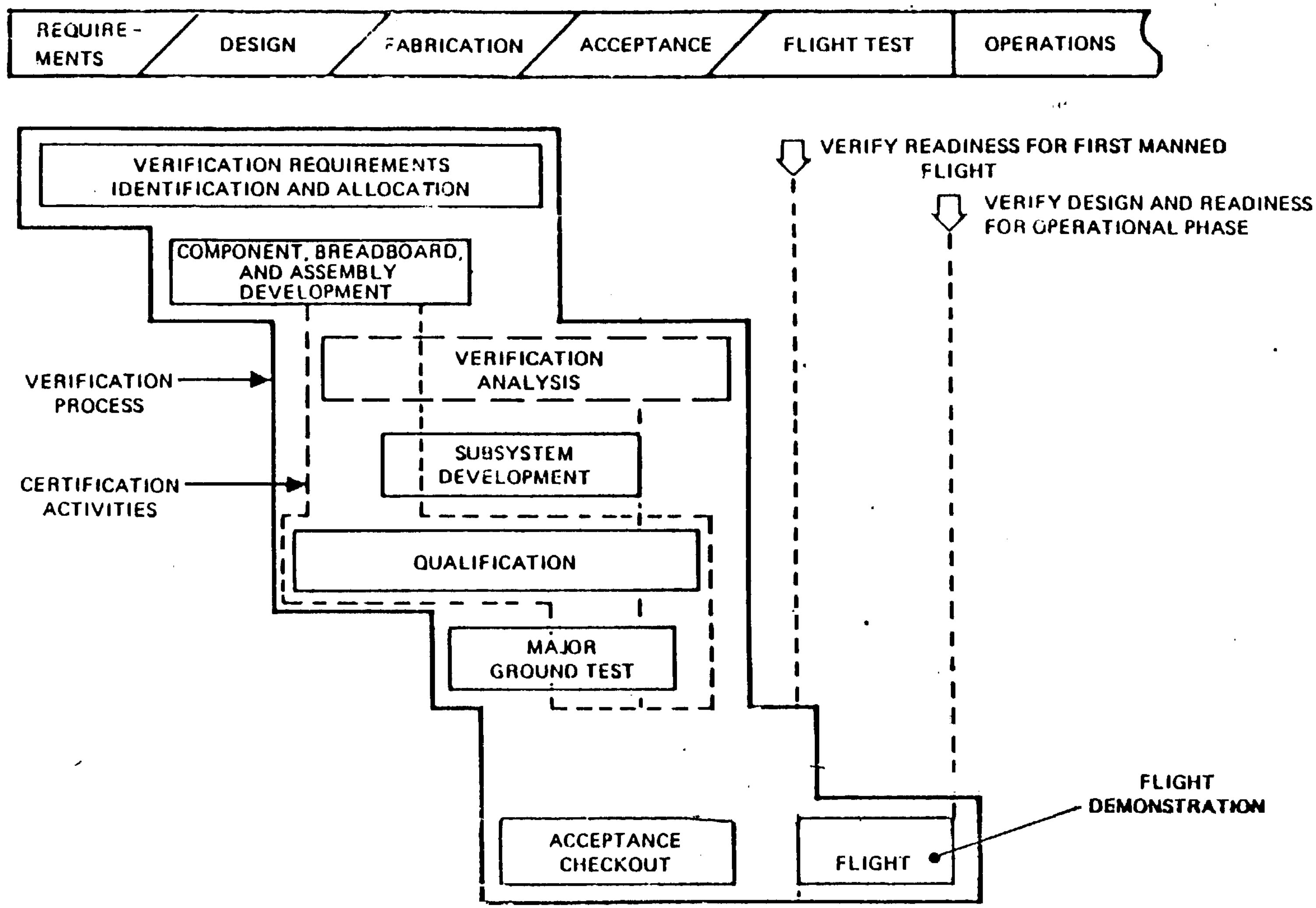


Figure 7-3. Major elements of the LRB test program.

testing does not generally include activities associated with the development and qualification of electrical and electromechanical piece parts because these activities are controlled by the Electric/Electronic/Electromagnetic (EEE) parts procurement process and the MSFC Approved Parts List (APL).

7.2.1 DESIGN VERIFICATION

Design verification will demonstrate that the designs meet documented performance and functional requirements and will include activities directed at the component, assembly, and system. The design verification activities will include:

a. Identification of LRB element and subsystem level performance and design requirements.

b. Allocation of the verification method to satisfy the requirements.

c. Definition and implementation of system, integrated systems, support equipment, and launch systems verification processes required to accomplish the design verification.

7.2.2 HARDWARE/SOFTWARE VERIFICATION

Verification will ensure that the LRB deliverable hardware and software, including support equipment, is built in accordance with released engineering, meets the Contract End Item (CEI) specifications, and is operable within the specified environmental ranges. This verification process is accomplished by inspections, acceptance tests, in-process tests during manufacturing and assembly, system functional tests, integrated acceptance tests, launch processing tests, and launch readiness tests. The verification process will include:

a. Identification of in-process test and inspection requirements that are consistent with the manufacturing build-up and assembly flow.

b. Identification of LRB component, assembly, and system level acceptance requirements.

c. Identification of all interfaces and development of the requirements that must be verified subsequent to component, assembly ,and system level deliveries.

d. Allocation of appropriate verification methods to satisfy requirements.

e. Definition and implementation of the specific inspections, demonstrations, analyses, and tests required to accomplish verification.

7.2.3 VERIFICATION REQUIREMENTS DEVELOPMENT

The verification methodology will be developed in parallel with the LRB design. The vehicle and system designs and performance objectives shall define all functions to be performed as well as required performance levels. Certification requirements, pass-fail criteria, and tolerances will be developed from the overall requirements. Verification requirements will be generated and assigned to ensure that the procedures for verification accomplishment are complete.

The LRB Verification Plan will contain a set of guidelines and criteria which will be used in the establishment of verification methods and assignments. These guidelines and criteria will provide uniformity in methods applications, ensure that low cost methods are always considered, and assure that critical systems will be verified by test. The guidelines and criteria will be developed early in the program to ensure they are available during the design and the verification requirements development efforts.

7.2.4 VERIFICATION METHODS AND PHILOSOPHY OF APPLICATION

The verification methods to be used on the LRB program include analysis, similarity, inspection, demonstration, and test. These methods are generally arranged in the order of flow from the beginning of hardware development to completion of flight testing. The degree to which a verification method or combinations of methods can be used will be based on the requirements. In general, the order of consideration and evaluation of verification methods will be to:

a. Determine whether analysis could be used in lieu of test.

b. Determine whether tests required for other purposes, such as acceptance tests, might be used in lieu of an additional special purpose test.

c. Define necessary analyses, inspections, demonstrations, and tests.

7.2.4.1 Analysis

Verification based on analysis, in lieu of testing or to support testing, will be implemented through methods such as engineering analysis, historical data extrapolation, math modeling, simulation, statistical evaluation, and prediction. Flight test demonstration will be limited to nominal flight conditions and verification of boundary and off-nominal conditions will be performed through analysis.

7.2.4.2 Similarity

Verification by similarity is the process of using the qualification documentation of an identical item that has been qualified for a similar application. We will use based on similarity (BOS) verification methods where it can be shown that the article under consideration is similar or identical in design, manufacturing, quality control processes, and use, to another article that has been certified previously to equivalent or more stringent criteria. Previous certifications will be thouroughly investigated. If it is determined that previous certifications were not at least as stringent as LRB requirements we will perform additional certification in the areas of new or increased requirements by one of the four other verification methods.

7.2.4.3 Inspection

Inspection shall be accomplished by review of applicable documents, specifications, drawings, and/or examination of hardware for compliance with requirements such as construction features, workmanship, quality, and dimensional requirements.

7.2.4.4 Demonstration

Demonstration is a verification method involving the use of mock-ups, displays, or other devices to show operation under actual or simulated conditions.

7.2.4.5 Test

Testing will be performed to provide quantitative data for performance verification of equipment under various specified environmental conditions. The evaluation of the test results will determine whether or not the element or system complies with the requirements. We will always employ the test method for critical systems, and it will be the method assigned as the verification method whenever a simpler, lower cost method is considered inadequate from the standpoint of technical risk. All tests will be identified in an Integrated Test Plan (ITP). Test plans, procedures, and reports will be approved by NASA/MSFC. The various types of tests that will be conducted during the LRB program are as follows:

a. Development Tests. These tests (Table 7-1) are engineering evaluations conducted to minimize technical risk, schedule impacts, or cost, and to support design and analysis. Development tests are not normally subject to the rigor and controls associated with the qualification process. They encompass material selection, failure modes and effects, performance, design tolerance, and identification of operational and maintainability characteristics and procedures. In cases where development tests are required for qualification, the intent will be declared prior to such tests and the necessary rigors and controls will be defined and implemented to ensure validation of the tests and data for the qualification process.

b. Qualification Tests. Where certification requirements cannot be met by analysis, BOS, inspection, or demonstration, one of the various test methods will be applied. Qualification tests are those tests conducted as part of the verification process to certify the design and to assure that the manufacturing process successfully creates products that meet requirements with adequate margins of safety and performance. These tests are conducted in accordance with formal test procedures and are covered by quality assurance procedures.

Qualification units shall be flight configuration hardware, except as modified to accommodate minor changes that may be necessary to conduct the test. Minor changes may be made to the hardware for test purposes, such as the inclusion of accelerometers, monitoring leads, strain guages, or thermocouples. The qualification item shall successfully complete acceptance testing prior to the start of the qualification test sequence. A functional proof cycle wil be performed after every major environmental test to ensure functional performance. Where incipient failures, wear, or untestable redundant paths are involved, we will provide, as a part of the qualification test plan/procedure, a post-disassembly inspection to provide the necessary

Table 7-1. LRB development tests (Preliminary list).

TEST	CONFIGURATION	POTENTIAL LOCATION
WIND TUNNEL		
Aerodynamic Wind Tunnel Pressure & Loads Test	Existing STS Model with LRB	NASA Facility/AEDC
Aerodynamic Wind Tunnel Stability & Control Test	Existing STS Model with LRB	NASA Facility/AEDC
Wind Tunnel Captive Trajectory Test	Existing STS Model with LRB	NASA Facility/AEDC
Base Heating/Recirculation Wind Tunnel Test	Existing STS Model with LRB	NASA Facility/AEDC
Aerodynamic Heating	Existing STS Model with LRB	NASA Facility/AEDC
STRUCTURES AND MECHANISMS		
Engine Gimbal Frequency Response Test	Fullscale Thrust Structure & Engine Simulators	GDSS/MSFC
Aft Skirt Structural Test	Fullscale Aft Skirt	GDSS
Model Firewall Test	Model Firewall	NASA/Commercial Labs
LRB Jettison Test	Subscale LRB & ET Simulator	GDSS
Forward Attach Fitting Load Test	Fullscale Forward Attach Fitting	GDSS
Aft Attach Fitting Load Test	Fullscale Aft Attach Fitting	GDSS
Separation Explosive Device Functional Test	Fullscale Separation System	GDSS
Engine Boot Material Heating Test	1/4 Scale Engine Boot	NASA/Commercial Labs
Nose Cone Material Heating Test	1/4 Scale Nose Cone	NASA/Commercial Labs
Tank Insulation Characteristics	1/4 Scale Tank	NASA/Commercial Labs
Welding Process Development Tests	–	–
A) Weld Coupons Tests	Weld Coupons	Subcontractors
B) Weld Joint Cyclic Load Tests	Weld Joints	Subcontractors
Component Development Testing (Rings,Domes,Baffles,etc.)	Fullscale Components	GDSS/Subcontractors

LRB DEVELOPMENT TESTS (LO2/LH2)

TEST	CONFIGURATION	POTENTIAL LOCATION
PNEUMATIC/FLUIDS		
LO2 Tank Pressurization System Test	LO2 Mockup Tank Pressurization System	GDSS
LH2 Tank Pressurization System Test	LH2 Mockup Tank Pressurization System	GDSS
LO2 Tank Outflow Test	1/4 Scale Tank Model	GDSS
LH2 Tank Outflow Test	1/4 Scale Tank Model	GDSS
Propellant Duct Capacitance, Delta P, Flow-induced Vibration	Fullscale Propellant Ducts	GDSS
Feedline Thermal/Acoustic Insulation Test	Tank Feedline Mockup	GDSS
Component Development Testing	–	–
A) Vent Valves	Fullscale Components	GDSS/Subcontractors
B) Feed Valves	Fullscale Components	GDSS/Subcontractors
C) Fill/Drain Valves	Fullscale Components	GDSS/Subcontractors
D) Disconnects	Fullscale Components	GDSS/Subcontractors
E) Ducts	Fullscale Components	GDSS/Subcontractors
F) Bellows	Fullscale Components	GDSS/Subcontractors
G) Joints	Fullscale Components	GDSS/Subcontractors
H) Pressure Regulators	Fullscale Components	GDSS/Subcontractors
I) Ground Pressure System Components	Fullscale Components	GDSS/Subcontractors

LRB DEVELOPMENT TESTS (LO2/LH2)

TEST	CONFIGURATION	POTENTIAL LOCATION
AVIONICS		
GN&C	–	–
A) Flight Control Processor (FCP)	DET Units in SIL	GDSS
B) Rate Gyros	DET Units in SIL	GDSS
C) Remote Voter Unit (RVU)	DET Units in SIL	GDSS
D) Motor Control Assembly	DET Units in SIL	GDSS
Instrumentation & Data System	–	–
A) Remote Data Unit (RDU)	DET Units in SIL	GDSS
B) Sensors	DET Units in SIL	GDSS
C) Harnessing	DET Units in SIL	GDSS
D) Propellant Loading Instrumentation System (PLIS)	DET Units in SIL	GDSS
Range Safety	–	–
A) Receiver	DET Units in SIL	GDSS
B) Decoder	DET Units in SIL	GDSS
C) Laser Firing Unit (LFU)	DET Units in SIL	GDSS
D) Batteries	DET Units in SIL	GDSS
E) Destructor	DET Units in SIL	GDSS
F) Antenna	DET Units in SIL	GDSS
Power Systems	–	–
A) Electro/Mechanical Actuator Power (Batteries)	DET Units in SIL	GDSS
B) Power Distribution Unit (PDU)	DET Units in SIL	GDSS
C) LFU	DET Units in SIL	GDSS
D) Harness	DET Units in SIL	GDSS
E) Booster Batteries	DET Units in SIL	GDSS
Component/Breadboard Testing	Breadboard Units	GDSS/Subcontractors

LRB DEVELOPMENT TESTS (LO2/LH2)

TEST	CONFIGURATION	POTENTIAL LOCATION
ENGINES		
Injector	Fullscale Injector System Test Rig	Engine Developer
A) Mixture Ratio	.	.
B) Ignition Stability	.	.
C) Throttling Characteristics	.	.
Thrust Chamber Assembly	Fullscale Thrust Chamber Assembly Test Rig	Engine Developer
A) Thermal Characteristics	.	.
B) Materials Selections	.	.
C) Erosion	.	.
Controller	Fullscale Controller Test Rig	Engine Developer
A) Thermal Environment	.	.
B) Control Algorithms	.	.
C) Response Characteristics	.	.
D) BIT/BITE Requirements	.	.
Nozzle	Fullscale Nozzle System Test Rig	Engine Developer
A) Cooling	.	.
B) Inertia	.	.
C) Gimbal Limits	.	.
D) Flex Mechanism	.	.
Thrust Vector Control System	Fullscale TVC System Test Rig	Engine Developer
A) Hydraulic System (Pumps,Lines)	.	.
B) Force Requirements	.	.
C) Response Characteristics	.	.
Throttling Device	Fullscale Throtteling System Test Rig	Engine Developer
A) Mixture Ratio	.	.
B) Response Characteristics	.	.
Component Development Testing	Full/Subscale Components	Engine Developer
GSE		
Model Flame Bucket/Flame Deflector Test	Model Liquid Engine/Flame Bucket & Deflector	GDSS
Launcher Operating Load/Deflection Test	GSE Launch Simulator Test Rig	GDSS
LO2/LH2 Line Retract Tests	GSE Launch Simulator Test Rig	GDSS
Rise-off Panel Test	GSE Launch Simulator Test Rig	GDSS

7/1C

verification information.

c. Acceptance Tests. These tests will be conducted in accordance with formal procedures, with full quality assurance coverage. Acceptance tests include performance demonstrations and environmental exposures to screen out manufacturing defects, workmanship errors, incipient failures, and other performance anomalies not readily detectable by inspection techniques or ambient functional tests. The test data will be approved by our quality assurance, test agency, and design engineering functions prior to acceptance of hardware or software. Upon satisfactory completion of the acceptance tests, the cognizant project office will conduct a final acceptance review and will take delivery of the completed item as noted on the DD-250.

d. Systems Integration Tests. Systems integration testing encompasses component, system, and integrated systems verification. Systems integration tests are conducted in a sequence that verifies components and systems individually, subsequently bringing these components and systems on line to verify total integrated systems performance. When completed, component and system level testing provide a verification of performance and interfaces of a particular element as it is integrated into the total LRB system. These tests are intended to verify fit, function, and total performance as higher levels of integration are achieved. The final test of the integrated systems verifies that all of the LRB systems perform their functions satisfactorily in the total integrated environment.

A preliminary list of special tests under consideration for the LRB program is contained in Table 7-2.

Table 7-2. LRB SYSTEM TESTS

TEST	CONFIGURATION	POTENTIAL LOCATION
AVIONICS		
LRB Avionics System Validation in SIL	LRB Avionics System	GDSS (SIL)
STRUCTURES AND MECHANISMS		
Acceptance Proof Test	Flight Weight Tank	MSFC/GDSS
Certification Burst Test	•	•
Tanking - Detanking Test	•	•
Full Scale Influence Coefficient Test	•	•
Vehicle Structural Test (Bending Loads, Torsion)	•	•
Vehicle Modal Survey	•	•
ACCEPTANCE TEST HOT FIRING		
Start Transients	Single Engine	Engine Developer/MSFC/NSTL
Stop Transients	•	•
ISP Verification	•	•
Nozzle Cooling	•	•
Gimbal System Verification (Damping,Inertia,TVC Loads Verification)	•	•
Hot Restarts	•	•
Total Thrust	•	•
Orificing	•	•
CERTIFICATION TEST HOT FIRING		
Mission Duty Cycles	Single Engine	Engine Developer/MSFC/NSTL
Firing Stability (Bomb Stability,Mixture Ratio)	•	•

7.2.4.6 Prelaunch Operations

Prelaunch operations verify the vehicle interfaces with the ground support systems, the ability to tank and de-tank, interfaces with the other elements to be launched, and culminate in the Flight Readiness Review. Prelaunch operations include the tanking and de-tanking tests, dry countdown demonstration test (CDDT), wet CDDT, flight readiness firing (FRF), instrumentation system performance, and other aspects of launch readiness. These tests are conducted by the KSC launch team with both contractor and NASA/MSFC support. Satisfactory completion of all pre-launch verification requirements will be required before a decision is made to launch.

7.2.4.7 Flight Performance

Verification of LRB flight performance is the ultimate goal of the Verification Plan. The LRB will be equipped with the appropriate development flight instrumentation to monitor and verify performance of all systems, the severity of the environments to which the vehicle was qualified, and to assure that LRB capabilities meet the design requirements. The flight performance shall be measured by compliance with flight parameters and procedures developed by NASA with support from the contractor. The recommended approach to flight test is described in Section 9 of this Implementation Plan.

7.2.5 RESULTS EVALUATION

The results of all verification activities will be evaluated against the performance criteria established prior to the verification process. Only after this evaluation confirms satisfactory vehicle performance will the verification requirement have been satisfied. Verification results will be evaluated against various tolerance levels. The tightest

LRB SYSTEM TESTS

TEST	CONFIGURATION	POTENTIAL LOCATION
HEAVY WEIGHT PROPULSION SYSTEM (BATTLESHIP TANK)		
Pressurization Tests	Non-Flight Weight Tanks, Propulsion Feed System,	MSFC/NSTL
Fill and Drain	Engines, Control Avionics, TVC System	"
Ground Pressurization and Relief System	"	"
Automatic Tanking Verification	"	"
Tank Outflow Tests	"	"
Full Scale Engine Cluster Firing	"	"
A) Mission Duty Cycles	"	"
B) Thermal Interaction	"	"
C) Manifold Performance (Flow Stability,Lines,Valves)	"	"
D) Start Flows	"	"
E) Full-Duration Firing	"	"
Thrust Vector Control	"	"
FLIGHT WEIGHT PROPULSION SYSTEM		
Engine Cluster, Feed/Fill/Drain System, Instrumentation & Control and Subsystems Performance Verification	Flight Weight Tanks,Propulsion Feed System, Engines, Control Avionics , TVC System	MSFC/NSTL

tolerances will be placed on the manufacturer's acceptance tests for LRB components. For systems tests, acceptable performance margins will be broadened, and during pre-launch tests margins will be widened further to actual flight levels. The method to be used to determine tolerance buildup will be the root sum square technique.

7.2.6 VERIFICATION COMPLETION

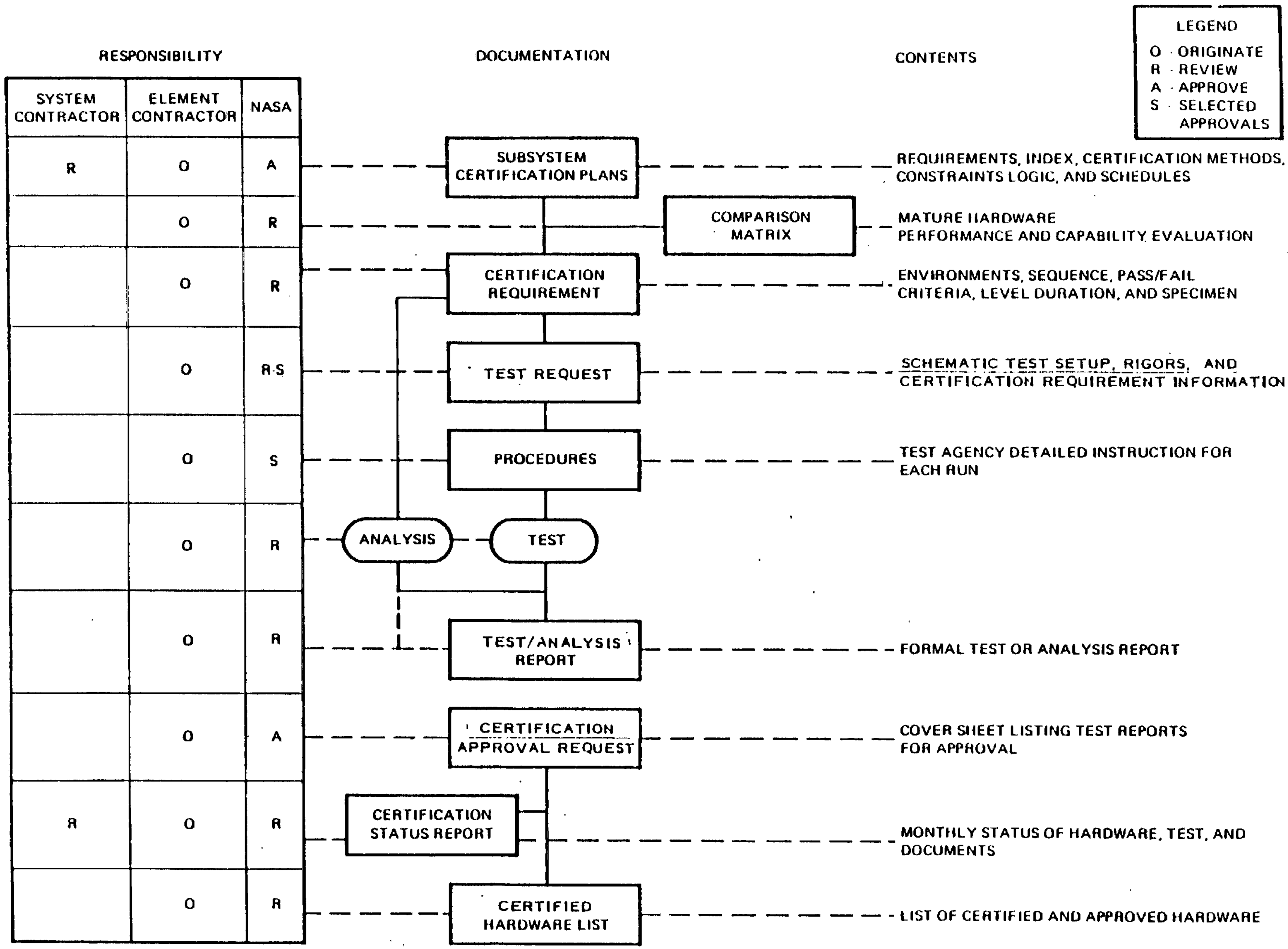
Verification will be documented in a formal manner. The total verification process documentation will provide for design knowledge capture and complete traceability of requirements, methods, and data to support subsequent change activities. A sample of the document flow for the verification process is shown in Figure 7-4.

7.2.7 VERIFICATION CLOSEOUT

A verification matrix will identify each requirement and specify which verification method will be used to satisfy the requirement. It willll identify the applicable test plan paragraph where verification by test is used and be used as an audit tool for closeout activity to ensure verification process completion. A verification report will indicate the test reports and analysis reports that satisfy the verification requirements and will specify action required to close out unresolved tasks.

7.2.8 CUSTOMER VERIFICATION CLOSEOUT

Customer verification reviews shall begin early in the program and will be conducted periodically throughout the program to ensure agreement between the customer and prime contractor. NASA/ MSFC will approve verified items and issue discrepancy reports in deficient areas of the verification process.


RESPONSIBILITY
DOCUMENTATION
CONTENTS
LEGEND
O - ORIGINATE
R - REVIEW
A - APPROVE
S - SELECTED APPROVALS
SYSTEM CONTRACTOR
ELEMENT CONTRACTOR
NASA
R O A
SUBSYSTEM CERTIFICATION PLANS
REQUIREMENTS, INDEX, CERTIFICATION METHODS, CONSTRAINTS LOGIC, AND SCHEDULES
O R
COMPARISON MATRIX
MATURE HARDWARE PERFORMANCE AND CAPABILITY EVALUATION
O R
CERTIFICATION REQUIREMENT
ENVIRONMENTS, SEQUENCE, PASS/FAIL CRITERIA, LEVEL DURATION, AND SPECIMEN
O R-S
TEST REQUEST
SCHEMATIC TEST SETUP, RIGORS, AND CERTIFICATION REQUIREMENT INFORMATION
O S
PROCEDURES
TEST AGENCY DETAILED INSTRUCTION FOR EACH RUN
O R
ANALYSIS
TEST
O R
TEST/ANALYSIS REPORT
FORMAL TEST OR ANALYSIS REPORT
O A
CERTIFICATION APPROVAL REQUEST
COVER SHEET LISTING TEST REPORTS FOR APPROVAL
R O R
CERTIFICATION STATUS REPORT
MONTHLY STATUS OF HARDWARE, TEST, AND DOCUMENTS
O R
CERTIFIED HARDWARE LIST
LIST OF CERTIFIED AND APPROVED HARDWARE

8
LAUNCH OPERATIONS

8.1 INTRODUCTION

There will be three major tasks associated with LRB ground operations: LRB checkout and flight certification, vehicle integration, and integrated Shuttle vehicle checkout and launch operations. To accomplish these operations, the existing Shuttle on-line launch facilities must be modified to accommodate the LRB. The facility modifications and start-up of LRB operations must be achieved with minimal impact on the ongoing Space Transportation System operations.

8.1.1 LRB CHECKOUT AND FLIGHT CERTIFICATION

Before the LRBs can be integrated with the Orbiter and ET, they must be certified for flight and fully checked to verify system integrity and compatibility.

To achieve maximum efficiency, it will be desirable to assemble the LRB in the vicinity of KSC, either on or off site. This approach would enable both final vehicle checkout and flight certification to be performed at the assembly site prior to shipment to the Vehicle Assembly Building (VAB) for integration with the STS. To properly record the flight certification of the vehicle, a documentation system that meets all KSC and MSFC requirements must be established. This system should be developed through working group meetings with the appropriate NASA personnel as shown in Figure 8-1.

After final assembly of the LRBs, the boosters will be checked out and flight certified at the assembly site (Figure 8-2). The checkout and flight certification will be to a level which complies with NASA STS requirements. The testing will also consist of compatibility tests with Launch Processing System (LPS) and the Orbiter. This will be done by either connecting directly into the LPS or using a LPS/Orbiter emulator that permits verification without requiring access to the LPS itself.

The test firing of the engines will take place at the National Space Technology Laboratories (NSTL) in Mississippi. If the engines are tested in the same manner as the SSMEs, they will be fired prior to assembly and then shipped to the assembly plant near KSC for integration. If certification requirements dictate that the engines be fired after integration with the LRB stage, then the LRBs will be assembled at KSC and shipped to NSTL for testing (Figure 8-3).

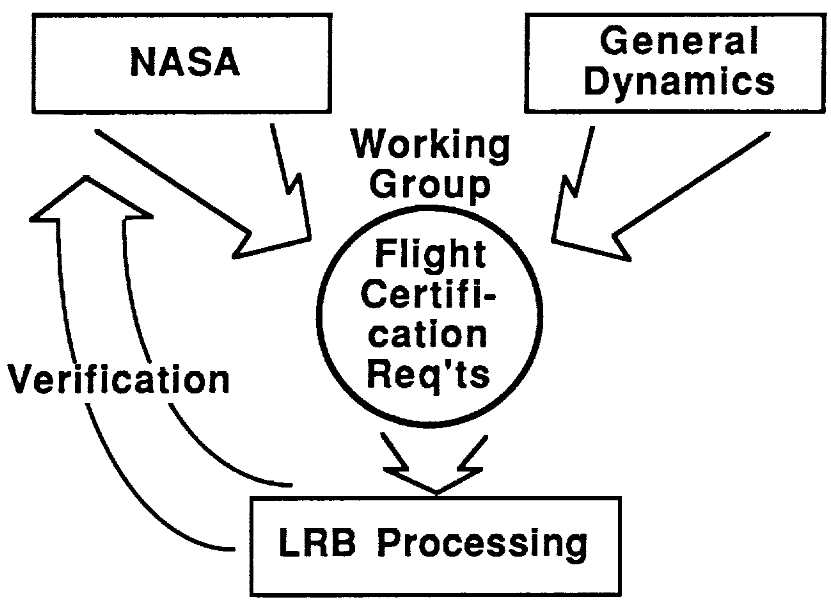


Figure 8-1. Off-site flight certification system.

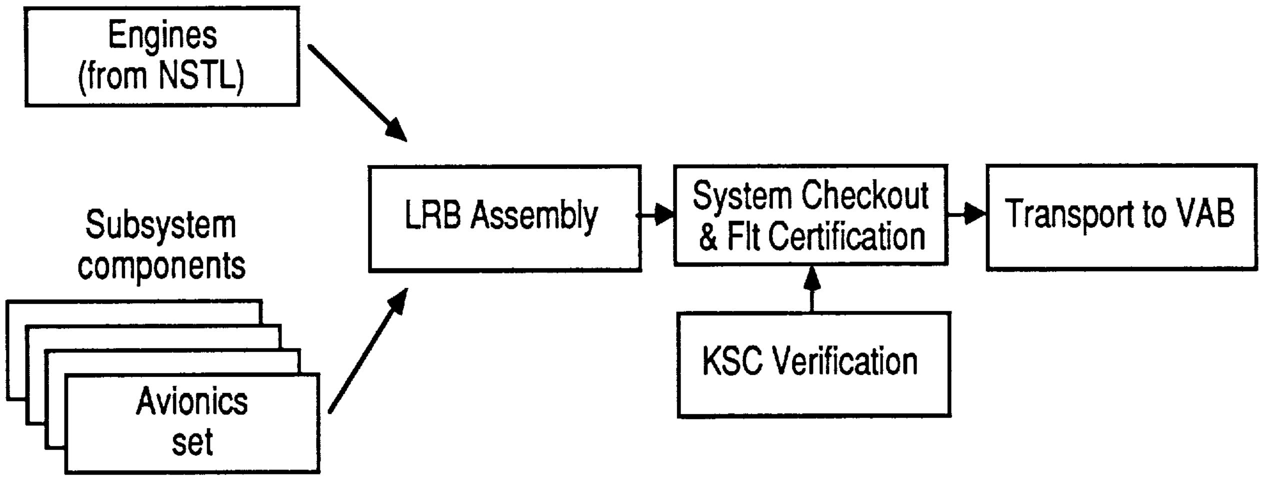


Figure 8-2. LRB Assembly, Checkout, & Flight Certification

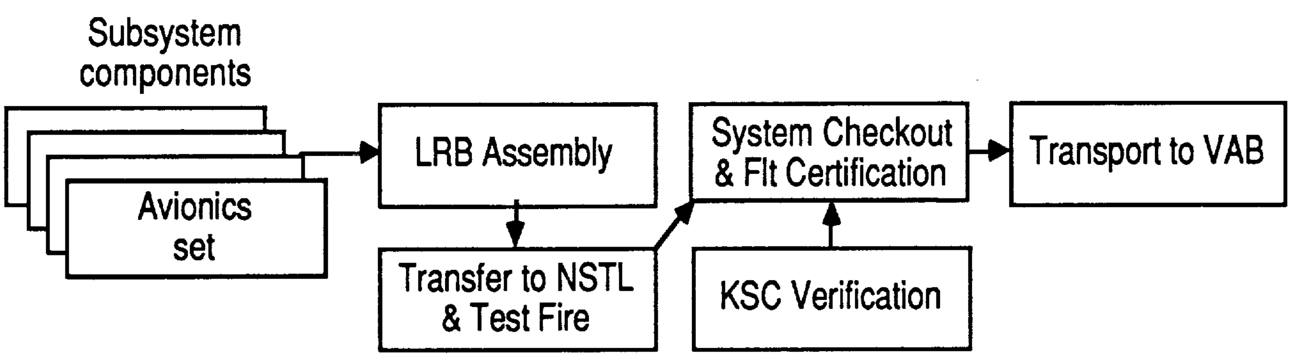


Figure 8-3. LRB Assembly, Checkout, & Flight Certification with Integrated Test Firing

8.1.2 VEHICLE INTEGRATION

Once final checkout and flight certification have been completed, the LRB will be delivered to the VAB transfer aisle. If delivered to the VAB horizontally, the LRB will be lifted and rotated to the vertical position before being placed on the MLP holdown system (see Figure 8-4). The LRB will then be mated to all the appropriate systems, such as data, fuel, ECS, and purge. Once the hookups are verified, the LRBs will be aligned and the ET mated, followed by the Orbiter mate.

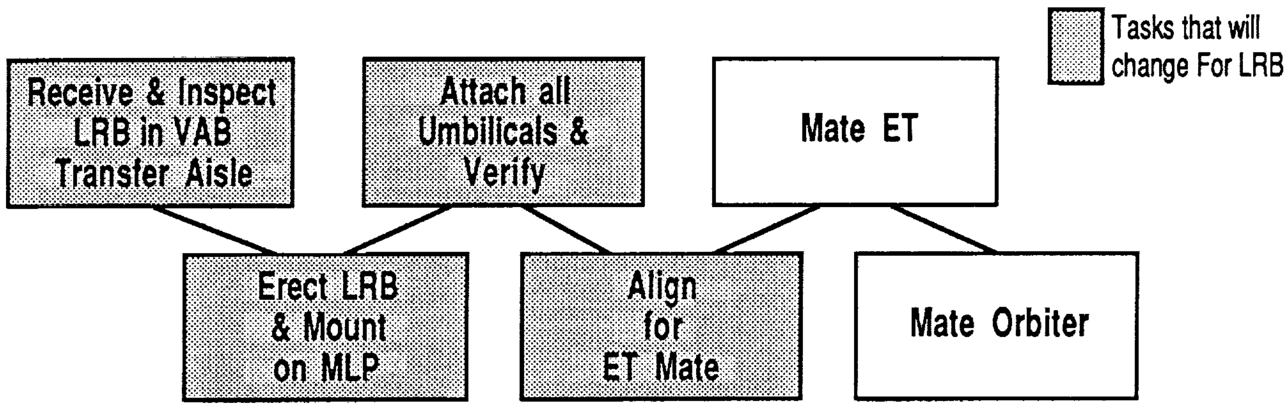


Figure 8-4. Vehicle integration

8.1.3 INTEGRATED VEHICLE CHECKOUT AND LAUNCH OPERATIONS

Once the system is fully integrated, there will be a Shuttle Integrated Test (SIT) to verify compatability and to test the fully integrated vehicle (Figure 8-5). The vehicle will then be transported to the launch pad, where payload integration and additional testing are performed. When these activities have been completed, launch operations begin. For the LRB this will consist of ordnance arming, battery installation, and fueling. If RP-1 is used as the primary fuel for the LRB, the vehicle will be fueled prior to or early in the terminal countdown. If LH2 is utilized, both LH2 and LO2 will be loaded in conjunction with the ET tanking near the end of the terminal countdown.

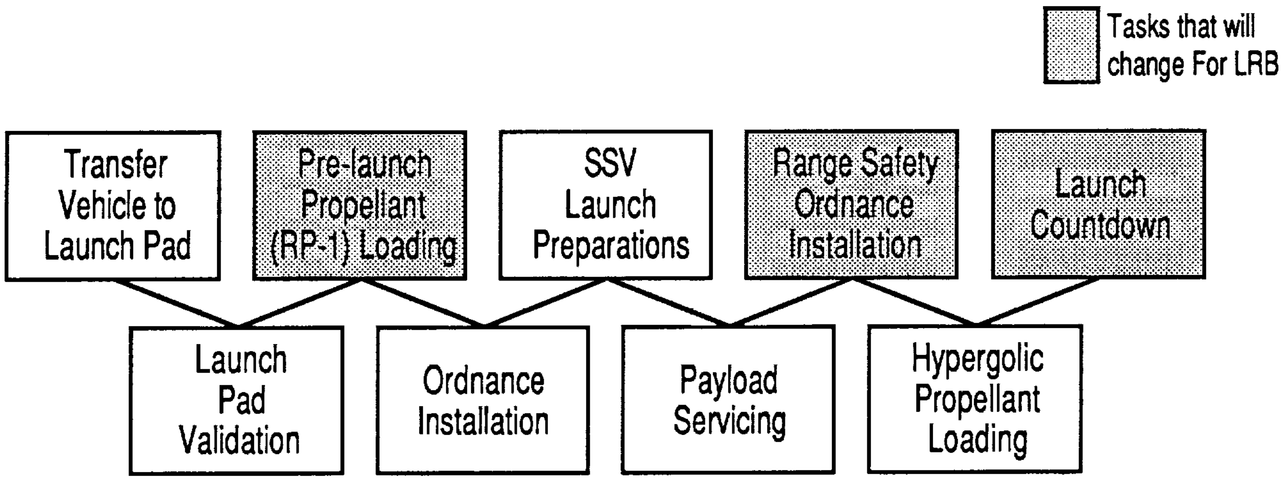


Figure 8-5. Launch pad operations

8.2 SCOPE

This section describes the effort required to activate and prepare KSC for processing the LRBs as described above. The implementation of LRB capability at KSC can be grouped into three broad phases: 1) modifications and additions to existing KSC facilities, launch support equipment (LSE), and ground support equipment (GSE); 2) modifications and additions to the KSC operations support system; 3) verification and validation of the entire KSC system prior to the first STS flight with LRBs.

8.2.1 FACILITY, LSE, AND GSE MODIFICATIONS

The existing launch processing facilities must be modified, as summarized in Table 8-1, to accommodate the greater size of the LRBs and to provide a propellant servicing capability at the launch pads. The principal facilities that must be modified are the Mobile Launch Platform (MLP), launch pad, Vehicle Assembly Building, LRB

Checkout Facility, and the Launch Processing System (LPS).

Table 8-1. KSC facility modifications.

	LO2/LH2 New Pump-Fed 5A	LO2/RP-1 New Pump-Fed 5D	LO2/RP-1 New Pressure-Fed 1B
VAB			
Platforms	New	New	New
MLP			
Propellant Service	Tee off ET LO2 & LH2 sys, new control skids	Tee off ET LO2 sys, new control skids new RP-1 system	Tee off ET LO2 Sys, new control skids new RP-1 system
Vent Mast (East)	New LH2	------	------
Launch Pad			
ET GOX Vent Arm	New	------	New
ET GH2 Vent Arm	New	------	New
Prop Store & Transfer	Existing LH2 & LO2, may add LH2 storage	Existing LO2, activate Apollo RP-1	Existing LO2, activate Apollo RP-1
Launch Processing System	Modify Prop Loading, Term Count.New C/O S/W and H/W	Modify LO2 load,term count. New C/O & RP-1 S/W and H/W	Modify LO2 load,term count. New C/O & RP-1 S/W and H/W

8.2.1.1 Mobile Launch Platform

Owing to the planned high usage of the existing MLPs and the scope of the MLP modifications required to accommodate LRBs, at least one new MLP will have to be built to support the LRB program. To minimize cost and schedule impacts, the basic existing MLP structural and dimensional design will be used as much as possible, and modified only as required for the LRB. Major MLP modifications required will include: a new propellant system, a new holddown system to provide a soft release for the STS, and enlarged flame holes for the larger LRB engine plumes. A key issue is whether to meet peak LRB flight rates solely by modifying an existing MLP or to build additional MLP units. We recommend deferring this decision until later in the program, when more detailed assessments of MLP usage, LRB design, and launch requirements can be made.

8.2.1.2 Launch Pad

The principal change to the launch pad will be the installation of new propellant storage and transfer systems. At this early stage of the program, three propellant combinations are still under consideration: oxygen/hydrogen (LO2/LH2), oxygen/RP1 (LO2/RP-1), and oxygen/methane (LO2/CH4). Since all three LRB configurations utilize LO2, we recommend tapping into the existing LO2 transfer system in the MLP, which is currently used to fuel the ET. This will require an LO2 propellant control skid in the MLP for each booster, LRB tanking control software in the Launch Processing System (LPS), Hardware Interface Modules (HIM) in the MLP to connect the control skids to the LPS, data interconnects between the firing room and the MLP, and a data and command interface between the LPS and each LRB booster.

Our baseline concept for the LH2-fueled LRB configuration is to tap into the existing ET hydrogen transfer system in the MLP, similar to the LO2 system described above. However, the existing capacity of the pad hydrogen storage tank will be insufficient to support both the ET and two LRBs. If additional storage is required, our recommendation is to add storage capacity but continue to utilize the existing cross-country transfer system. Using the existing transfer lines will significantly reduce the total system boiloff losses by having to chill down only one transfer system. A vent system to carry the GH2 boiloff from the LRBs to the hydrogen burn stack must be provided on the pad.

RP-1 cross-country transfer piping from the Apollo program still exists at both pads, but has not been used for over a decade and would have to be renovated, cleaned, and certified for LRB operations. RP-1 storage tanks exist on pad LC-39A, while pad LC-39B will require a new storage tanks. An RP-1 servicing capability must be added to the MLP to provide a connection from the pad RP-1 system and the LRB fuel interface. A control skid with the proper LPS software and HIMs will be required, similar to the LO2 system.

If methane (CH4) is used, a completely new fuel storage, transfer, LPS control, and MLP servicing capability must be added.

In addition to the propellant storage and transfer systems described above, the launch pads will also require other modifications, which will vary depending on the final LRB configuration chosen. Because the LRBs using hydrogen, pressure-fed RP-1, and methane are significantly longer than the present SRBs, the LRB tanks would interfere with the ET GOX vent arm, which presently extends over the left-hand SRB during pre-launch pad operations. If any of these LRB configurations are selected, this vent arm will have to be modified in a manner that it will enable it to "wrap around" the LRB. If the LRB diameter exceeds 14 feet, as is the case for some of the concepts currently under consideration, the LRB will also interfere with the existing ET hydrogen vent arm, which attaches to the ET in the intertank area. Selecting the LH2 or pressure-fed LRB will require a modification to the vent arm to preclude interference and provide suitable launch clearances. This change may also require changing the hydrogen vent location on the ET.

8.2.1.3 Vehicle Assembly Building (VAB)

Integration of the STS flight elements is presently done in Highbays 1 and 3 of the VAB by stacking the SRBs on the MLP, mating the ET to the SRBs, and connecting the Orbiter to the ET. During this integration process, access to the STS elements and the completed STS stack is provided by movable work platforms which extend to enclose the entire STS. Because these platforms are designed specifically for the STS with SRBs, the different dimensions of the LRBs will require modification to the platforms. The platforms will have to be modified to accommodate the larger diameter LRB. The "flip-up" dimensions will also have to be changed to permit the STS with the larger LRBs to pass by as the STS exits the VAB. In addition, the upper level platform, which now fits around the ET, will have to be changed to fit around the longer LRBs as well as the ET.

8.2.1.4 LRB Checkout Facility

Accommodations for final checkout and flight certification for the LRBs must be provided at KSC. If the LRBs are to be delivered completely assembled from a distant location, a temporary storage and checkout capability will be needed. This would require facilities with access to LPS or an LPS emulation checkout test set and sufficient space for checkout equipment. If the LRB final assembly facility is built at KSC, the checkout and flight certification capability can be designed into the new facility, thereby adding efficiency to the ground processing of the LRBs.

8.2.1.5 Launch Processing System

The addition of the propellant systems at the launch pads described above will require new LPS software and interface hardware, including launch consoles, to provide control and monitoring of the ground propellant systems and to interface with the LRBs to control and interact with their on-board systems during propellant loading. Additional LPS software and hardware will also be required to control and interact with the LRB during all other ground checkout and integrated operations, including final countdown and launch.

8.2.2 OPERATIONS SUPPORT

In addition to the hardware and software changes already described, another major element in implementing the LRB launch capability will be to develop and maintain the operations support system. One of the primary tasks will be the development of new or modified Operations and Maintenance Instructions (OMI) to provide procedures for all the LRB related ground processing. Included will be stand-alone LRB checkout and modified OMIs for the integrated processing tasks that will be changed for LRB compatibility. The launch crew that will process the LRBs must be trained and certified prior to processing the first flight LRBs.

8.2.3 VERIFICATION AND VALIDATION

The final phase of the KSC activation process will be to verify and validate all changes. This will begin with such tasks as validation of the LRB LO2 systems that tee off the existing ET LO2 systems, and will conclude with the last validation test for the STS/LRB system: the Flight Readiness Firing (FRF), involving a normal STS countdown and firing of all Orbiter and LRB engines, but inhibiting STS release. This test will validate that the ground and flight systems play together properly up to liftoff and will validate all of the STS systems.

8.3 APPROACH

Because the LRBs will be Shuttle elements, the primary responsibility for integrating the LRBs into the STS ground processing system will normally reside with KSC, with major support from Marshall Space Flight Center and the LRB contractor. This section describes the approach that GDSS will take to insure proper support to KSC.

8.3.1 MODIFICATION PHASE

The primary responsibility of the LRB contractor during the KSC modification phase will be to provide timely LRB ground processing and GSE and facility requirements to KSC, so that the launch site preparations can be accomplished to support the initial LRB processing. The first step in establishing the requirements will be to develop a functional ground flow to depict each major element in the LRB ground processing, such as receipt, inspection, checkout, terminal countdown and launch. For each of these functional elements, GDSS will define the LRB support requirements and KSC will define the KSC requirements, such as safety. From these requirements, the details of the functional flows can be defined, GSE and LSE design specifications can be developed, and any required changes to the GSE, LSE, or LRB can be identified early in the development process.

To accomplish the above tasks, a great deal of requirements information must flow freely between MSFC and its LRB contractor and KSC and its contractors. A primary vehicle for transmitting these data wiill be working groups, chaired by one or more of the NASA centers and involving the appropriate STS and LRB contractors. It is expected that working groups will be established to address such subjects as Ground Operations, Countdown, Fluids, and Avionics. The working groups will allow free flow of technical data between the responsible engineers, assignment of action items, and agreement on issues common to several STS elements, such as LO2 flow rates to each of the LRBs. Table 8-2 shows the likely division of responsibilities for launch site modifications.

Table 8-2. Likely division of responsibilities for launch site modifications.

Kennedy Space Center	• Design and construct new MLP • Design and build all integrated processing GSE permanently installed at KSC • Design and accomplish facility modifications • Design, acquire & install LSE • Develop LPS software • Establish and maintain LRB OMRSD • Develop and modify OMIs
Marshall Space Flight Center/ LRB Contractor	• Provide LRB requirements for GSE, LSE, facilities, & operations • Develop on-board checkout/launch systems compatible with KSC ground systems • Design & build transportation, handling, off-line checkout, & maintenance GSE

8.3.2 VERIFICATION AND VALIDATION

Prior to processing a flight vehicle through KSC, the modifications to KSC facilities, hardware, software, and support systems must be validated. To verify the physical interfaces and clearances, GDSS will provide two LRB pathfinder vehicles which will have the same physical dimensions and interfaces as the flight vehicles. The pathfinder LRBs will be processed through the KSC facilities using the preliminary OMIs developed by KSC from the LRB requirements and will serve to identify any incompatibilities between the facilities, the GSE, the LRB or the OMIs. During this process, GDSS will provide an engineering team to resolve and approve any required changes.

Our approach to verification will be to first conduct functional tests of individual components and to progress logically to total integrated system checkout. An example is our approach to verifying the liquid propellant storage, loading, and drain capability and the required propellant system controls, one of the principal areas of change required to accommodate the LRBs at KSC. After testing the components in the propellant transfer systems, we will conduct a cold flow test — flowing LO2 from the storage tanks through the existing transfer system to the MLP and through the two new LRB "tees," to ensure that all hardware and software interact and control the flow properly. Finally, the ET and the LRBs will be loaded with propellants using the hardware, software, OMIs and launch crews as a final validation of the propellant systems.

All of these tests will use the new hardware and be controlled by the new LPS and LRB software. Because the LPS and LRB control software and the data exchange between the two is so critical to safe propellent loading, GDSS will provide an LRB Avionics Simulator to validate the systems prior to the ET/LRB tanking. Throughout the process of validating KSC implementation, GDSS will provide an engineering and operations support team at KSC. The team will have the engineering expertise and authority to approve all engineering and operational changes required to ensure full compatibility between the KSC and LRB systems.

8.4 LAUNCH OPERATIONS INTEGRATION

KSC will develop and maintain Interface Control Drawings for all of the LRB facility interfaces. The ICDs will be reviewed by a NASA working group, consisting of KSC and its contractors, MSFC, and its LRB contractor team. The primary interfaces of concern are actual physical connections between the LRB and facilities, physical clearances between the LRB and facilities, and data exchanges between the LRB and the ground facilities during ground processing and launch.

9
MISSION OPERATIONS SUPPORT

9.1 SCOPE

The LRB prime contractor will support the critical NASA functions of mission planning, operations, and analysis by developing LRB flight requirements and constraints, analyzing LRB mission performance, and by supporting NASA/MSFC and the STS Program in accomplishing these functions for the integrated launch vehicle. During the LRB flight test program, additional tasks will be required, including definition of flight test requirements and comprehensive analysis of mission data. Our goal is to establish a certified operational envelope at the end of the test program. These responsibilities will be carried out under the coordination of the SE&I organization and will include support of all LRB Project technical groups.

9.2 MISSION PLANNING AND PREPARATION

The LRB prime contractor will support NASA in a variety of pre-launch tasks, beginning with assistance in definition and implementation of the STS-LRB flight test program and continuing throughout the operations phase with support for Flight Readiness Reviews.

9.2.1 FLIGHT TEST

The test program currently envisioned will require four test flights of the STS-LRB configuration. Successful completion of these test flights will constitute final verification of the LRB and of the integrated launch vehicle. Our recommended flight test program is based on the following:

a. Conservative build-up of flight conditions to assure safety is not compromised during the initial flights.

b. Demonstration of nominal system performance by the end of the test flight program.

c. Validation of the engineering data base and analytical models for use in verification by analysis of the full flight envelope, including dispersed performance and environments as well as failure and contingency cases.

9.2.1.1 Flight Test Requirements

The STS-LRB flight test program will have a number of objectives. These objectives will include demonstration and verification of the following key in-flight capabilities:

a. Compatibility of the LRB with other STS elements.

b. Achievement of mission performance capability.

c. Ability to provide specified thrust time histories.

d. Achievement of nominal performance of all LRB subsystems in the flight environment.

e. Verification of induced structural and thermal environments.

f. Safe LRB separation.

These primary objectives will be expanded to detailed requirements through analysis by experienced test engineers in the Test and Evaluation group. This activity will include definition of test techniques and instrumentation, data analysis and analytical tools required, and data required from other program elements. This will be documented in a preliminary *LRB Flight Test Plan* that will be coordinated with NASA to develop the integrated flight test plan including the approach for build-up of flight conditions. Final requirements will be documented as Flight Test Objectives for assignment to specific missions.

9.2.1.2 Flight Envelope Expansion

Initial LRB flights will be planned in a conservative build-up of flight conditions to provide maximum practical protection against unanticipated events or conditions. The specific strategy for achieving this build-up will be developed thirough analysis of system margins for the LRB as well as for other elements of the integrated launch vehicle. This build-up could include such features as a reduction in performance requirements to protect against dispersions and to provide extra margin to allow shaping the trajectory to reduce critical loads and system stresses. Additional limitations on environmental conditions such as winds, ground ambient temperature, and moisture might also be imposed.

9.2.1.3 Flight Test Analysis and Reporting

Detailed analysis of data from the four test flights will confirm the safety and performance of the LRB and of the integrated launch vehicle. The General Dynamics LRB project office will perform this analysis for the LRB and all LRB subsystems, using data from the Orbiter Operational Instrumentation downlink as well as from the Development Flight Instrumentation (described further in Section 9.2.1.4). If applicable, recovered flight hardware will be inspected as part of our test analysis. Comprehensive mission reports will be submitted to NASA/MSFC covering all aspects of LRB subsystem and interface performance. To the greatest extent possible, analytical tools required for this analysis will be developed and proven during ground tests.

A major part of mission analysis will involve element interfaces and integrated launch vehicle performance and induced environments. Existing analytical tools developed by NASA/MSFC and Shuttle System Integration, and proven on previous STS flights, will be used to provide this data. General Dynamics will support NASA in determining modifications necessary to these tools for analysis of the vehicle with LRBs. The LRB prime contractor will also participate with NASA and its contractors in analysis of integrated launch vehicle performance and interface conditions, including interpretation of LRB performance and conditions.

Another major requirement for analysis will be the establishment of a database for validation of system math models, both for the LRB and for the integrated launch vehicle. In many cases this will be the most demanding requirement for establishing analysis plans.

9.2.1.4 Flight Test Instrumentation

It is anticipated that a Development Flight Instrumentation System (DFI) will be installed on each LRB. These systems will be used during the test flights to supplement operational data from the Orbiter Operational Instrumentation (OI) downlink and will be time-synchronized to that system for data correlation. Features of the DFI will include:

a. Strain gauges, accelerometers, and pressure transducers to determine structural loads.

b. Microphones to determine acoustic environments at selected locations.

c. Temperature measurements to determine the thermal environments of selected structural subsystem elements.

d. Other required information not provided via the OI.

9.2.2 MISSION DESIGN

Effective mission planning will require integration of the capabilities and constraints of all STS-LRB elements. A basic objective of LRB development is to maintain compatibility with existing integrated launch vehicle constraints, thus preserving the base of knowledge developed in previous STS flights. General Dynamics will support NASA mission planning and design activities by providing a comprehensive definition of LRB requirements and constraints, tailored to mission design and operations, and by supporting NASA in defining and verifying modifications to existing operational tools such as the Abort Region Determinator. General Dynamics will also assess mission plans for LRB compatibility.

9.2.2.1 LRB Mission Capabilities and Constraints

As stated in Section 9.2.1, our objective is to establish a verified operational envelope for the LRB subsequent to the flight test program. Accomplishing this and documenting it in a controlled, usable form, will facilitate NASA's mission planning and reduce LRB project support required for mission preparation. Because many LRB conditions are derived from integrated launch vehicle effects, it will be necessary to accomplish this in conjunction with NASA.

We expect to work with NASA through the existing Systems Integration Review panel structure to allow definition of critical parameters and the optimum form for their use. Similar coordination of ground and flight test results will allow development of LRB and integrated launch vehicle capabilities and constraints. The increased complexity, capabilities, and alternatives to flight operations will require new flight rules and procedures to be developed and carefully evaluated, including updates to the launch commit criteria. In conjunction with the new flight rules and procedures, new software must be developed, tested, and certified to reflect these changes. After approval by NASA, these will be placed under strict configuration control.

9.2.2.2 Mission Design Support

As specific missions are defined, support will be provided in flight design/procedures development, software reconfiguration/certification, and training and simulations. Each area will be reviewed for compatibility with LRB limitations and capabilities and modified accordingly.

Exceedances, low margin conditions, and unverified conditions will be studied as appropriate. Such studies will be conducted with other program elements as appropriate, such as to see if the addition of LRB throttling capability and the possibililty of different LRB thrust profiles change the area over which the external tank operates.

It is anticipated that efficient mission design will require "tag" values to define performance of the specific hardware end items assigned to each flight. Parameters such as engine thrust and specific impulse, defined from engine acceptance tests, could provide more accurate planning data than specification values. It is assumed that the LRB liftoff and ascent loads environment for the payloads is the within the same envelope as the present system, and therefore should be transparent to the payloads community.

In conjuction with the modified flight rules and procedures, software must will need to be reconfigured and tested for the use in the Shuttle Avionics Integration Laboratory (SAIL) and Shuttle simulators. This development will be accomplished per the Systems Integration Schedule D.

As new flight rules and procedures are established, training workbooks and simulation scenarios must be updated to reflect these changes. Flight crews and flight control operators will be trained in the new ascent procedures required by the the more complex LRB control functions.

9.2.3 MISSION ASSESSMENT

As specific missions are defined, the LRB project office will conduct a comprehensive assessment of the capability of assigned LRB hardware to meet mission requirements. This will be accomplished in three parts, as follows:

a. Performance and Environment - Data provided by the System Integration Contractor will define the trajectory parameters including LRB performance requirements and the induced environment. These data will be used to assess structural loadings, thermal environments, separation conditions, and other critical parameters for both nominal and abort conditions. Flight margins will be defined for each parameter. Support to NASA for day of launch commit-to-flight decisions requires the development of "load indicators" that reliably reflect the effect of measured wind profiles on critical structural elements. Real time mission support will be required to evaluate results of this analysis.

b. Avionics Interfaces - Participation in planning, conduct, and review of data from NASA's Shuttle Avionics Integration Laboratory (SAIL) will provide assurance of the hardware and software interfaces in the simulated mission environment.

c. Ground Operations - Review of the planned LRB ground operations at KSC will be conducted to identify and assess any unique activities or interfaces that are expected.

9.2.4 FLIGHT READINESS REVIEW

The LRB project office will support NASA's objectives of assuring mission success and safety by conducting a comprehensive grass-roots Flight Readiness Review (FRR). The internal LRB project FRR will utilize informal working meetings within each organization to assess readiness for flight. These informal meetings will be followed by a Project Review, chaired by the project manager, in which each organization will report on readiness for their assigned area of responsibility and submit Certifications of Flight Readiness. A corporate review board will conduct an independent summary review after completion of the Project Review. It is expected that NASA will participate in both the project and corporate summary reviews.

After completion of the corporate review, General Dynamics will support the NASA FRR activities by providing data packages and summary briefings that address the following:

a. Results of the Mission Assessment described in Section 9.2.3, to assure compatibility of the assigned hardware with the mission requirements and environment.

b. Review of test and assembly records to identify anomalies and corrective actions to assure integrity of the assigned hardware.

c. Review of the as-built versus as-designed hardware to assure the assigned hardware conforms to the documented, verified design.

d. Review of all configuration changes since the previous flight to understand possible impact on system performance and ground and flight operations.

e. Readiness of the operations team assigned to support ground and flight operations.

9.3 MISSION ANALYSIS

After completion of the flight test program, our post flight analysis will be reduced in scope. Data received from the Orbiter Operational Instrumentation downlink will be analyzed to accomplish the following:

a. Verification of LRB system performance within normal limits.

b. Identification and investigation of anomalies.

c. Verification that LRB interfaces and induced environment conditions are within documented limits. We will support NASA as needed in the investigation of unexpected or out of tolerance conditions.

d. Support to NASA in analysis of integrated launch vehicle performance, to define LRB characteristics utilized in system dispersion analyses.

Mission summary reports will be developed for each flight.

APPENDIX 3

LRB/SRB TRANSITION PLAN
PLAN

SRB/LRB TRANSITION PLAN

CONTENTS

Section	Subject	Page
1.0	INTRODUCTION	1
1.1	Background	1
1.2	Objective	1
2.0	SCOPE	1
2.1	Requirements	1
2.2	Schedule Constraints	2
3.0	APPROACH	4
3.1	LRB Interface with SRB/STS	4
3.2	Facility Modifications and Acquisition	4
3.2.1	Mobile Launch Platform	5
3.2.1.1	Holddown and Release System	8
3.2.1.2	Exhaust Holes Design and Fabrication	8
3.2.1.3	Propellant Servicing System (MLP Segment)	9
3.2.2	LRB Assembly and Checkout Facility	10
3.2.3	Vehicle Assembly Building Modifications	11
3.2.3.1	Work Platforms	11
3.2.3.2	Avionics and Instrument Checkout Equipment	13
3.2.4	LC-39 Pad Modifications	15
3.2.4.1	Propellant Storage and Servicing Facilities	15
3.2.4.2	Fixed Service Structure Swing Arms and Vents	18
3.2.4.3	Support Equipment	19
3.2.5	Launch Control Center Modifications	20

3.2.5.1	Launch Processing System	20
3.2.5.2	Software Development	20
3.2.5.3	Dual Flow Management	20
3.3	Ground Support Equipment Acquisition	20
3.3.1	LRB Transporter	21
3.3.2	Lifting and Rotation Devices	21
3.3.3	Special Test Equipment and Tools	21
3.4	Operations Support and Logistics	21
3.4.1	KSC Manpower Impact	23
3.4.1.1	Training and Certification of Personnel	23
3.4.1.2	Dual Flow Manloading	23
3.4.2	Documentation Development and Verification	24
3.4.3	Integrated Logistics Support System	24
3.4.3.1	Logistics Engineering and Logistics Support Analysis	25
3.4.3.2	Logistics Management Information System	29
3.4.3.3	Maintainability Analysis	30
3.4.3.4	Provisioning and Procurement	32
3.4.3.5	Transportation and Handling	33
3.4.3.6	Training	34
4.0	VERIFICATION AND VALIDATION	35
4.1	Cold Flow Tests	36
4.2	Pathfinder Tests	36
4.3	Tanking Tests	36
4.4	Operational Readiness Inspection	36
4.5	Flight Readiness Firing	37

SECTION I

1.0 INTRODUCTION

In Section 8 of the Implementation Plan some of the requirements to activate and prepare KSC for processing the LRB's are identified and discussed. This transition plan is an expansion of those ideas and how they will be accomplished, phased-in, and integrated to assure that manpower, facilities, and equipment are in place at the right time to support first LRB launch.

1.1 Background - A principal LRB program goal is to develop the flight vehicle concurrently with preparation of the KSC launch facilities for the flight test program. Accomplishing this goal will depend on timely management decisions to identify flight vehicle configuration, payload weights, and mission profiles. Once these key decisions have been made the launch site transition can proceed. KSC has traditionally been responsible for all transition activities at the launch site.

1.2 Objective - The objective of this transition plan is to provide guidance to management and implementers alike so that coherent decisions can be made, and coordinated use of resources can be exercised to achieve the desired goals. Further, it is an objective of the transition plan to facilitate the most economic expenditure of funds and still maintain the highest standards of safety, quality, and efficiency during the modification, acquisition, and flight test phases of the transition.

SECTION II

2.0 SCOPE

This plan describes the actions necessary to establish an LRB launch capability at KSC and support the flight test program. It does not cover actions at the manufacturer's facilities, NSTL, MFSC, or movement of the LRB to KSC.

2.1 Requirements - The primary requirement is to transition KSC capability to launch the LRB/STS while at the same time continuing the SRB/STS program without slowdown until the LRB/STS is able to carry scheduled payloads into space. Actions to accomplish this can be grouped as follows:

a. Modifications and additions to existing KSC facilities.

b. Modifications or additions to existing KSC launch support equipment (LSE) and ground support equipment (GSE).

c. Modifications and additions to the KSC operations support systems (ie; manpower, training, logistics, software, etc).

d. Verification and validation of all changes and/or additions to assure compatibility with existing systems and operations, to comply with all NASA safety and product assurance criteria, and to complete necessary confidence-building demonstrations.

2.2 Schedule Constraints - The transition of KSC capability to launch LRB's is constrained at the outset and at the finish by the flight article development schedule. Figure 2-1 is a master schedule of the major categories of KSC transition activity leading to first launch.

LRB TRANSITION MASTER SCHEDULE

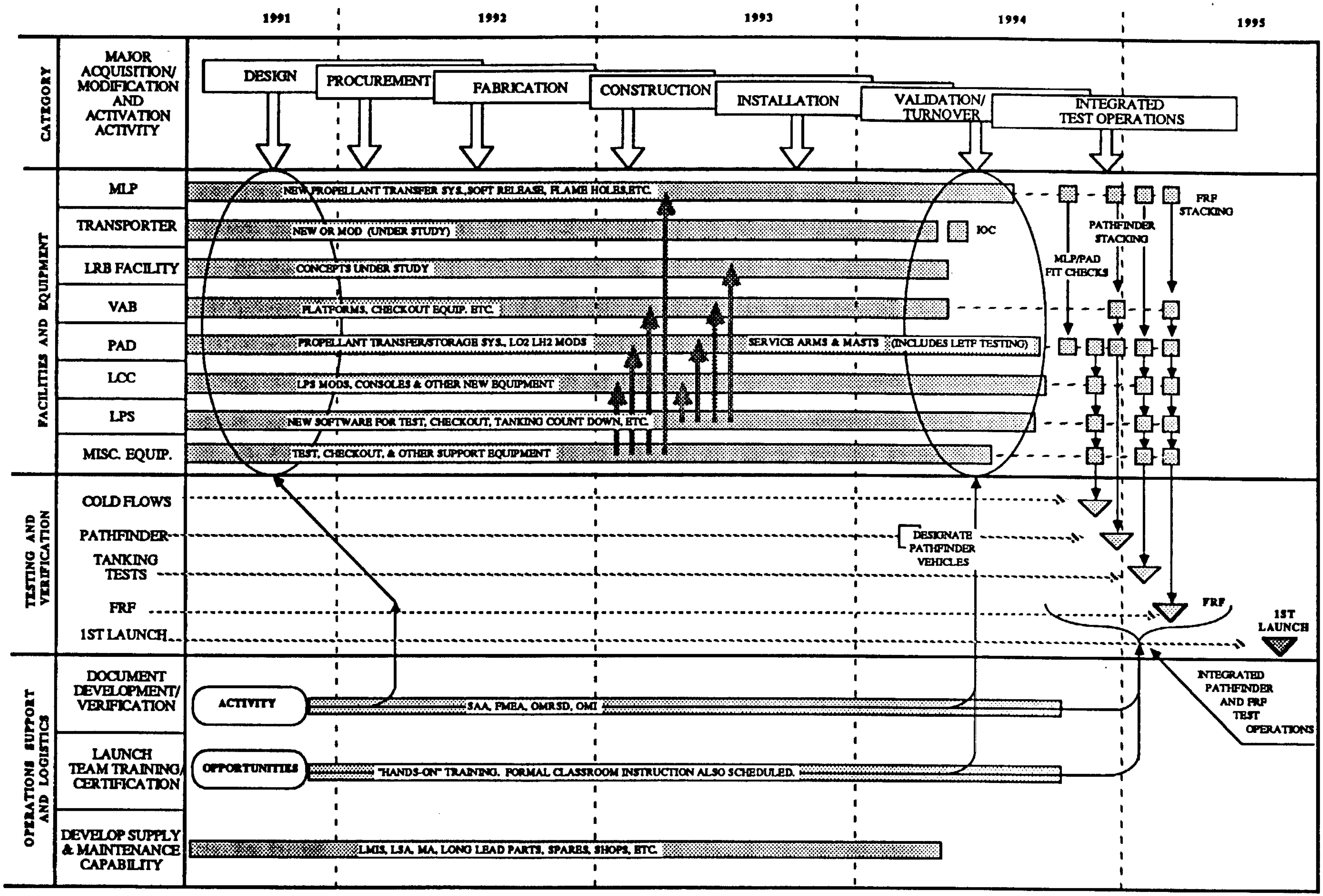


FIGURE 2-1

SECTION III

3.0 APPROACH

Although the pacing factor in the LRB program is usually thought to be the development of the flight article, any delay in initiation of transition activity at KSC could impact the planned first flight date. GDSS will participate in a timely information exchange with NASA and its contractors so that design specifications will be readily available for facility and equipment modification or acquisition. Management and execution of the transition activities at KSC is a KSC responsibility. The approach taken herein is to describe what must be done and how to do it without specifically designating who will accomplish the individual tasks. Delegation and performance of necessary work will be in accordance with program and contracting decisions. Each major category of activity will have its timelines and milestones to facilitate integration.

3.1 LRB Interface with SRB/STS - Throughout the LRB transition period at KSC, modifications to facilities and/or equipment in place or the addition of new equipment will require that whoever is performing the transition tasks be ever aware of the on-going Shuttle launch program. Any place where there is an interface between LRB and SRB activities due care must be exercised to assure the dual-flow nature of the two programs being conducted simultaneously. This is especially true on the pad during pre-launch processing and countdown. For example, fail-safe devices and procedures must be included to make it impossible for the wrong software to be used in the LPS. Strict control of ICD's during the transition design phase will aid in the development of adequate OMRSD's for coordination with existing operations procedures. OMI's must accommodate procedures for proper use of interchangeable equipment and facilities. Since it may be necessary to use the same personnel on both programs in some operations, safeguards must be developed to minimize the risk of human error in such a side-by-side situation.

3.2 Facility Modifications and Acquisition - Every effort will be made to use existing facilities. Where modifications are required, the design activities will consider the dual-use (ie; SRB/STS and LRB/STS) requirements, where possible, and include "murphy-proof" and fail-safe interfaces. Since the SRB/STS launch schedule will require the use of the three existing mobile launch platforms (MLP), design and acquisition of a fourth MLP will be required to support the flight test program. Modifications to the VAB, Launch Pads, and LCC will require careful scheduling to allow for on-going operations. Following are descriptions of concepts and some "how-to" solutions for getting the job done.

3.2.1 Mobile Launch Platform - The mobile launch platforms (MLP) currently supporting the STS with Solid Rocket Boosters (SRB's) are modified Saturn Launcher/Umbilical Towers (LUT) that have been in service for more than twenty years. Major modifications were made to satisfy the Space Shuttle requirements. Modifications included were:

a. Removal of the umbilical tower and hammerhead crane
b. Removal of the Saturn hold-down arms and blast shields
c. Cutting different exhaust holes for the SRB's and the Orbiter Main Engines
d. Installing SRB hold-down posts and Orbiter tail service masts (TSM)
e. Installing a major modification to utilize water as a sound suppressor and coolant

Further modification of the existing MLP's may not be practical. The repeated heating and cooling of the MLP's has caused warping and cracking of the deck. Metal fatigue is not unlikely under these extremes of thermal and mechanical stressing and stress reversals. The major structural changes needed for adaptation of the MLP's to the LRB's may not be feasible from a sound engineering or financial viewpoint or for dual interchangeable use with both SRB's and LRB's. At some time during the LRB development or transition from SRB to LRB employment, a modification program could be initiated if further analysis shows that modification is feasible. In the interim, it is essential that a new MLP be designed and acquired specifically for the LRB's.

KSC will likely proceed with design, construction, outfitting, and verifying the new MLP in a straightforward manner. For whoever is assigned the responsibility by contract, the first step will be to assure that lessons learned and technological advances available are considered in designing the new structure. Specific criteria will be used to retain as many existing interfaces as possible, and safety and efficiency will be improved. A more rigid MLP structure will be needed to accommodate stresses during engine thrust build-up and launch, or in the event abort on the Pad is necessary.

Included in the detailed design criteria for the MLP will be the impacts of the selected LRB configuration such as booster size and weight, number and type of engines, chosen propellants, support/hold-down requirements, control/monitoring equipment and the vehicle flexibility. To produce the most efficient and adaptable MLP, requirements for the SRB's will not be considered if they compromise the design in any way, unless management directs otherwise. Development of the detailed design requirements will be a joint NASA/GDSS task. The MLP will be designed for maximum stiffness to help offset the normal tendency of a liquid propellant booster to be less rigid than a solid propellant booster. During the dynamic analyses of the integrated vehicle and potential operating conditions, extendable columns and soft release systems will be considered for use.

Action will be taken to assure that all of the NASA and NASA contractor experience (i.e. Reynolds, Smith, and Hills and LSOC) with design, acquisition, and use of the existing MLP's is incorporated into the requirement and design of the new version.

The proven NASA acquisition process will be utilized. In addition to pertinent industry and government design and acquisition documents, the KSC-DE-512-SM "GUIDE FOR DESIGN ENGINEERING OF GROUND SUPPORT EQUIPMENT AND FACILITIES FOR USE AT KENNEDY SPACE CENTER" will be used.

KSC will assure that the NASA design review process is followed, that fabrication complies with industry and government standards and FAR's, and that logistics engineers are integrated into the design process as early as possible. Quality control and inspection will be key elements in the design and acquisition of the MLP, from design initiation through launch. Verification will be performed at specific milestones in the acquisition process, with final fit check and systems checkouts to be performed using a pathfinder LRB/STS.

After the basic structural design is under way, the general arrangement layout of service facilities (ie; additional propellant service masts, etc.) and the integrated space vehicle support equipment and systems will be prepared. Space will be allocated, physical locations assigned, and detailed plumbing and electric circuitry will be included.

Construction and outfitting will be serial, with minimum overlap. Outfitting can be by individual system contractor, by an installation contractor, or perhaps the most efficient methodology will be to have the Launch Operations Contractor (LOC) install equipment and verify that the design requirements have been met. This will be done before validation that the equipped MLP meets all operational requirements. The result of using the LOC in this manner should result in a shorter learning curve and allow the LOC (presently LSOC) maximum time to gain expertise with the new MLP and equipment. Figure 3-1 is a schedule showing the approximate time to complete the major events to activate a new MLP.

If assigned to perform the design task, GDSS can call on the General Dynamics Electric Boat Division for assistance to take advantage of the technology available in that organization. They have experience in designing and building complex launch support structures, including nuclear powered submarines.

LRB NEW MLP ACQUISITION SCHEDULE

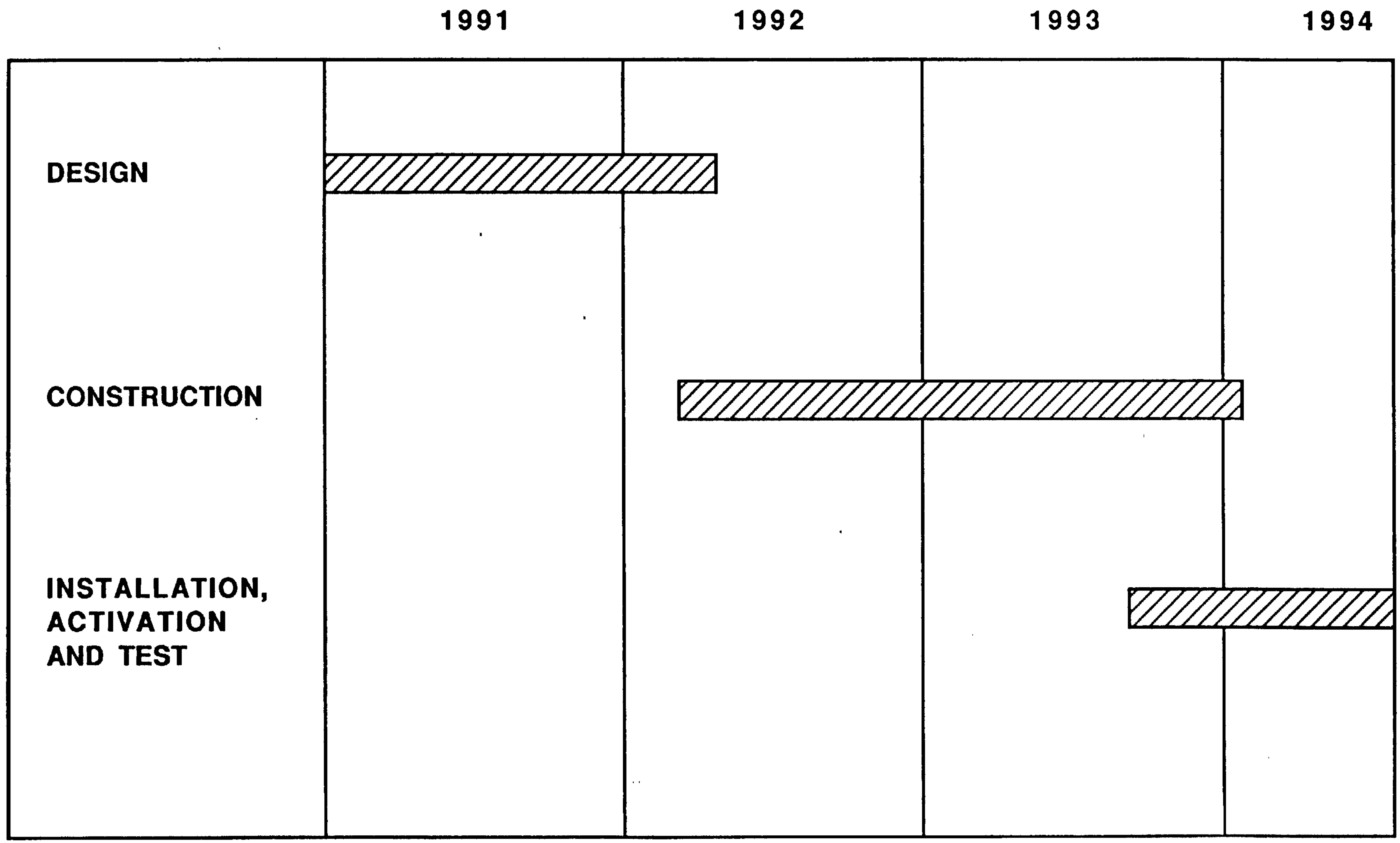


FIGURE 3-1

3.2.1.1 Holddown and Release System - One of the major challenges during the design of the new MLP will be providing a satisfactory system to support and hold down the LRB and to effect a soft release for liftoff after all engines have achieved full thrust. The present release system in use by the SRB/STS has functioned successfully for each launch. The Saturn V release system used a method of cold drawing metal rods to reduce shocks and vibrations resulting from suddenly releasing the flight vehicle after the thrust of each engine had been verified.

Although the flexibility of the LRB's is greater than the SRB's, the simplicity and reliability of the present STS support and explosive bolt release system warrant consideration for use. If used, a square support ring will bridge the LRB flame hole and permit very short spherical bearings to support the booster skirt at four places (mid-way between rocket engines). Each support will be adjustable and have a bolt through the center of the bearing. Restraining the skirt will be a frangible nut containing small explosive charges. Over these nuts will be debris catchers to assure fragments can not escape. By having a stiff support ring and short supports above the ring, flexibiity will be minimized.

Despite steps mentioned above, there remains a likelihood that the release of the tensile forces generated by the eight booster and three orbiter engines will allow a snap action that will produce adverse shocks and vibrations into the flight vehicle at liftoff. The Saturn V method of cold drawing metal rods can minimize these affects. Each rod can be shaped to furnish the desired force/distance profile, that is, maximum restraint at first motion decreasing to zero at the rods end. The number of rods and their profiles will be determined by detailed analysis. Several rods will be distributed around the booster skirts and located as near the support/holddown points as convenient.

3.2.1.2 Exhaust Holes Design and Fabrication - The original exhaust holes in the early Launcher/Umbilical Towers (LUT) were designed and then cold and hot flow tested as scale models to assure the satisfactory performance of the Saturn V vehicle, LUT and Flame trench combination prior to the first launch. Back pressure, base heating, and flame recirculation were explored to assure adverse conditions would not endanger the launch vehicle. Studies of the potential LUT temperatures, rocket exhaust pressures, and induced vibrations were used for designing, testing, and developing measurement programs to verify the design requirements were adequate and actual conditions were in compliance. The holddown period for engine thrust build-up and verification was very critical in not damaging the vehicle or LUT and equipment. When the LUT was modified to accommodate the Shuttle it was renamed the MLP.

The Shuttle, with the solid boosters that require no holddown except that needed during SSME runup, have much less potential for similar problems. Since the Orbiter/ET location and relationships on the MLP are unchanged, there will be no changes to the Orbiter/SSME flame hole location on the MLP.

Once the center lines of the LRB's are established in relationship to the Orbiter/ET, the design of the LRB flame holes can be formalized. Conflicting requirements can be resolved into the best compromises, however the location of the Orbiter/ET must not change. Smooth exhaust gas flow can be attained by having large openings and no changes in direction. Exhaust heat flux influences the designer to move structure away from the exhaust flow, but sound structural design practice requires the supports be placed under the loads, especially if rigidity is desired. Smaller holes will permit a stiffer MLP. The use of existing pad flame deflector and flame trench is a design criteria. The LRB exhaust holes will be kept as small as convenient to allow minimum eccentric loads on the cantilevered haunches supporting the rigid square ring on which the flight vehicle rests. The main structural supports for the flight vehicle through the ring and haunches are the twenty-five foot girders. The flame holes will be lined with "fire box" quality sheet steel backed by insulation that will protect the load carrying structural members. The design criteria for the MLP exhaust holes is the same whether applied to a new MLP or modification of the existing ones. Water is presently available in large quantities at the pads, therefore sufficient water is available for cooling and sound suppression, if needed.

Fabrication will necessarily be done at KSC, so a construction site must be selected that is accessible to the crawler-transporter and fabrication work activities, but which will not interfere with on-going Shuttle launch operations. If large quantities of steel are to be moved by rail, the site should be close to the KSC railroad system. The use of existing NASA design and review procedures and the application of KSC-DE-512-SM will assist in the orderly activation, testing, and transition of the LRB/MLP.

3.2.1.3 Propellant Servicing System (MLP Segment) - Launch Complex 39 has a twenty-five year history and has more propellant servicing capability than is now being used. The approaches developed and proven by time will be followed where practical in the design and implementation of LRB modification. The thermal protection system (TPS) on the orbiter is very sensitive to impact. Snow or ice denser than 14 pounds per cubic foot will possibly damage the TPS. Therefore, it is mandatory the cryogenic systems do not permit ice formations that could be dislodged and fall or be blown against the orbiter TPS. The following steps, if pursued, should facilitate the design and fabrication of changes necessary to accommodate the LRB servicing on the MLP:

a. Design the MLP propellant support equipment and facility modifications using STS Program Documents and the KSC Design Requirements such as KSC-DE-512-SM. These documents will effect minimum changes to the operations and propellants systems consistent with the latest technology and maximum utilization of existing hardware and software. The operator will be requested to participate in all phases of the design/acquisition process.

b. Assure the NASA design review process is followed and that safety, reliability, quality, maintainability, and logistics engineers are involved in the development of the design from the preliminary phase to the Operational Readiness Inspections.

c. Use the NSTS Launch Processing System (LPS) methods and the propellant monitoring and control software as guides in the development of new requirements and software. Control of the propellant systems will be largely from the signals furnished by point sensors on the LRB's i.e. at the 2%, 98%, 100% load points in each propellant tank. Software sub-routines used in checking flight and ground subsystems will be as identical to the LPS software as possible.

d. Develop and enforce a plan to assure complete inspection, design verification, and testing are performed on the hardware and computer software, and that adequate documentation and spares are available to the operator at system turn-over.

e. Involve the operator in every design/development step and invite participation in all testing to assure operator inputs are considered and to minimize any training requirements to achieve proficient operations.

f. Verify the design and hardware of each modification or new piece of equipment that interfaces with or could impact the flight vehicle is qualified. The Launch Equipment Test Facility (LETF) will be used to prove the acceptability of each critical support item prior to installation on the MLP or at the Pad. Examples of items to be tested are vent arms and the propellant service masts.

g. Plan to use non-flight LRB's such as structural/dynamic or propulsion test boosters as facility check out vehicles (or pathfinders). The Enterprise could possibly be made available to validate the total flow and physical and functional hardware flight vehicle to ground interfaces. Two test boosters are required for a "full up" series of propellant systems tests to demonstrate as closely as possible the capability of these systems prior to mating with and servicing the first flight article.

h. Be ready to furnish sustaining engineering support throughout the life of the program.

3.2.2 LRB Assembly and Checkout Facility - Pending the decision by LRB program management to adopt a "ship assembled" or "ship in segments" modus operandi, definitive planning for a facility at KSC for the assembly and checkout of the LRB must be postponed. If assembly and checkout are to be performed at KSC in existing facilities, the VAB center isle in the low bay is the only place where the horizontal work mode can be exercised. To use this space, it will be necessary to re-align the Solid Rocket Motor (SRM) processing flow. If the LRB is shipped assembled and only needs checkout prior to rotation for mating on the MLP, checkout could be performed temporarily on the barge, or the VAB transfer isle can be used for this purpose. If a new assembly and checkout facility is authorized, it will be necessary to obtain funding from extraordinary sources since the normal Construction of Facilities (C of F) cycle will not accommodate present estimated schedules.

3.2.3 Vehicle Assembly Building (VAB) Modifications - The major impact the LRB will have on the configuration of the VAB will result from the increased size of the LRB over the SRB, which will require modification of the access stands and platforms. Also, some additions and/or changes will be required to the electrical/electronic checkout and test equipment now in use to check out SRB's after stacking on the MLP.

The following goals previously established should be observed in the planning for the design and implementation of modifications within the VAB.

a. The modifications should accommodate either the SRB's or the LRB's interchangeably.

b. The launch schedule should not be affected by the installation of the modifications.

c. Modification work in one high bay will not impact integration effort in the adjacent bay.

d. The Orbiter and the External Tank (ET) location and access will not be affected by any modification.

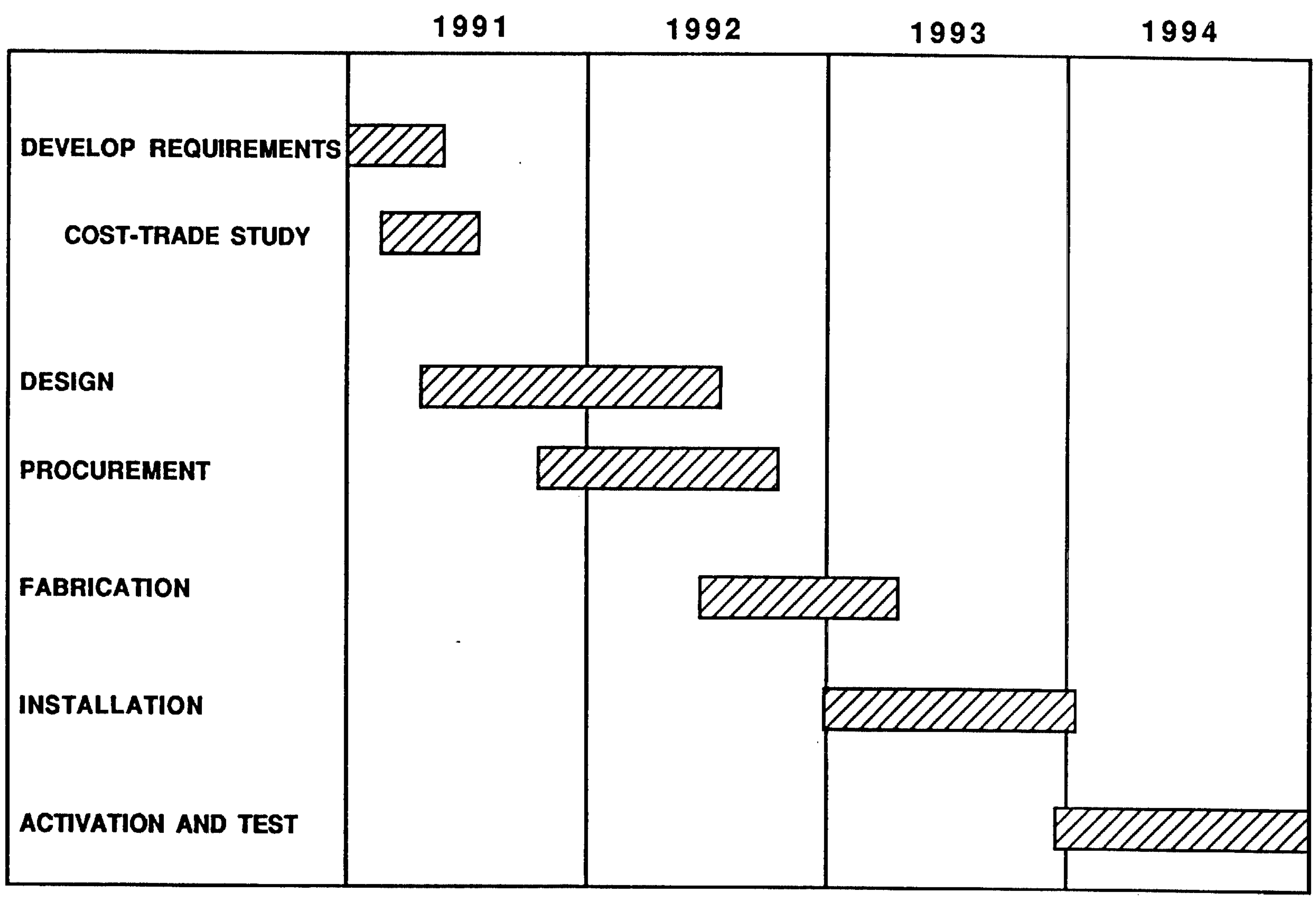
The KSC/SPC-LOC have indicated a single open period may be found for modifications within the VAB, however, the approach should not be dependent on a schedule opening that could vanish because of changing launch pressures, or other unforeseen events. Figure 3-2 is a tentative schedule of VAB modification work.

3.2.3.1 Work Platforms - The VAB high bays 1 and 3 have been outfitted with access platforms required during the integration of the Space Shuttle using SRB's. Presently, nine levels are available for access to the booster, orbiter, and ET. Each will be affected when the new LRB is processed in the VAB. Minimum modifications likely are:

a. The increased diameter of the LRB over the SRB requires that all nine existing work levels have larger cut outs.

b. The increased LRB length will probably require additional work levels within the VAB to access all areas of the new boosters.

VAB MODIFICATION SCHEDULE (PRELIMINARY)



Removal of basic platform steel will be necessary to assure adequate safety clearances with the flight hardware at all levels. Cutting and welding activities would likely impact operations in the adjacent bay if done within the VAB.

Whoever is selected by NASA to do this job should:

a. Perform a cost trade study as part of the preliminary design of platforms which meet the requirements of both the SRB and the LRB Shuttles. Consider an adjustable filler deck system that can serve a large selection of diameters with some variation in centerline locations. This will permit future shuttle configuration changes to be processed with minimal impacts.

b. Define the impacts to individual platforms (usually containing multiple working levels).

c. Design the required modifications in accordance with NASA design and review practices.

d. Develop firm schedules based on SRB operations. Design activities should focus on the number of basic platforms that are available and suitable for modification.

e. Determine the minimum number of basic platform structures that will have to be bought and initiate acquisition action.

f. Arrange for staging, erection, and platform modifications at a site near the VAB. The platforms should be converted to their new configuration without impacting on-going operations.

g. Complete the platform removal/installation planning and execute the work program. One or two platforms at a time can possibly be removed between shuttle occupancy dates in the VAB and new platforms installed without impact to operations.

h. Support the Operational Readiness Inspection and turnover. Assure that all required data are available and that initial spares are on hand (if required).

3.2.3.2 Avionics and Instrument Checkout Equipment - It may be possible to adapt to use with the LRB some of the generic equipment now being used in the VAB for checkout of SRB/STS electrical/electronic, and instrument sensors and systems. However, it will be necessary to procure and install LRB system-peculiar and specialized equipment. A safety problem could arise from side-by-side installation of these test sets, consoles, cables, adapters, connectors, etc. It is imperative that design of these devices include safeguards to prohibit improper use. Connectors should not be interchangeable, and a color system should be used; one for the LRB, one for the SRB, and one for common and multi-use checkout equipment.

Prior to rotation and mating of the LRB, some checkout work will be done with the LRB in the horizontal position. Mobile or portable equipment will be required for this effort. OMI's for operation of this equipment must include cautions and instructions for maintenance and care since movement of sensitive instruments can cause them to become unreliable. Specifications for this type equipment must include requirements for extraordinary ruggedness.

After rotation and mating of the LRB with the ET and Orbiter on the MLP, additional electrical and electronic checks will be required. Fixed equipment at the various levels in the VAB can be provided for this purpose. However, it must be designed to include the "murphy-proof" requirements discussed above, and it must be located so that it will not interfere with SRB/STS checkout procedures when the shuttle configuration changes. Provisions must be included for installation of this equipment during periods when the high bay is not occupied, or in such a manner that it will not interfere with SRB/STS assembly and checkout.

3.2.4 Launch Complex 39 (LC-39) Pad A & B Modifications - Changes to the configuration of the launch pads will be required to accommodate LRB propellant storage, transfer, and interface with the MLP. Provisions must be made on the pads to connect these new systems to the LPS computer complex in the LCC. Also, some changes must be made to the fixed service structures to accommodate the additional size and venting requirements of the LRB. These modifications and additions will require careful planning and scheduling to avoid conflict with the STS launch schedule. It is expected that no changes will be required to the rotating service structures (RSS), since one of the constraints on the LRB program is that there must be no impact on the RSS cargo changeout room and its interface with the orbiter. Figure 3-3 is a schedule of work required to modify the LC-39 pads.

3.2.4.1 Propellant Storage and Servicing Facilities - The LC-39 pads each have a 900,000 gallon liquid oxygen (LOX) storage tank, LOX vaporizer, two 1500 gallon per minute (gpm) pumps and almost 1500 feet of six inch vacuum jacketed (VJ) transfer line that interfaces with the MLP LOX plumbing. In addition there are two 10,000 gpm pumps and almost 1500 feet of 14 inch uninsulated transfer line, now deactivated, that were used by the SATURN V Program. The NSTS uses the smaller pumps and the VJ line.

Present LOX storage will likely be adequate to supply the LRB's if future growth is modest. The present pumps and transfer line can support the orbiter/ET and the LRB's by extending the loading time. Alternatively, the existing, preserved, 10,000 gpm pumps and the uninsulated transfer line could support the LRB's with some LOX quality degradation and transfer inefficiencies.

The best long range solution will probably be to keep the LOX loading time about the same as it is now for the orbiter/ET and maintain the same high quality LOX to the LRB rocket engines. To accomplish this, two 5000 gpm pumps (with motors, controllers, and accessories) and an eight inch foam insulated cross country transfer line will be required for the LRB's. This requires a new

LC-39 PAD A AND B MODIFICATION SCHEDULE (PRELIMIARY)

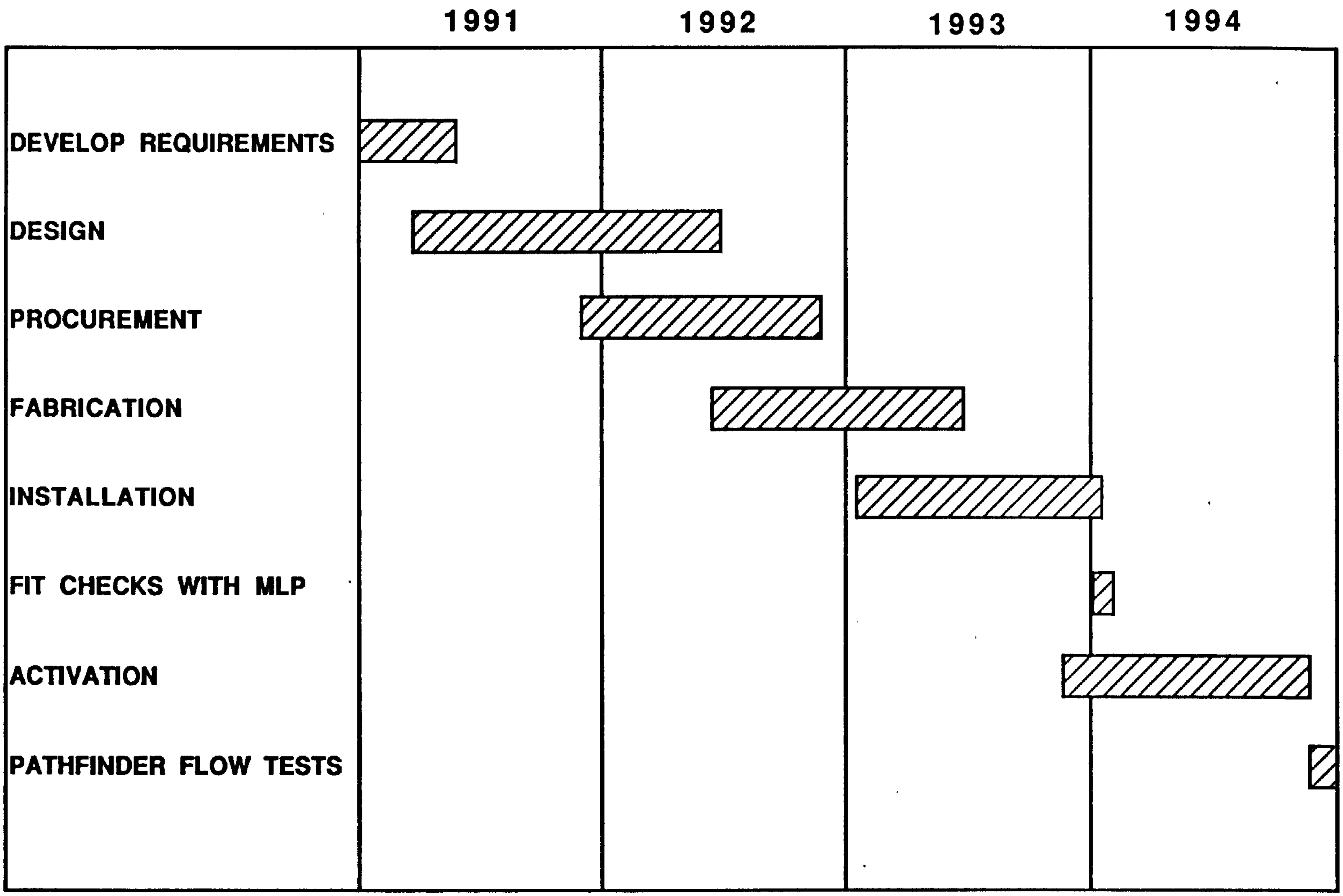


FIGURE 3-3

Pad-to-MLP interface. The existing six inch VJ line with a 1500 gpm pump is capable of replenishing the ET and the LRB's at the same time and will assure top quality LOX to both.
An additional tower may be required on the east side of the MLP to support a gaseous oxygen (GOX) vent arm that will probably be needed to assure there are no ice formations adjacent to cold gas vents on the LRB's. The western LRB GOX vent can be reached by an arm from the fixed service structure (FSS). The GOX vent arms may be avoided if an arrangement and location can be found that will assure there is no possibility of ice forming at the vent or if ice were to form, there is no possibility it could strike the Orbiter's TPS.

Propellant flow to each service mast on the MLP will be modulated by a throttling valve which will be controlled by the LPS. The control will be based on time and feedback from LRB liquid level point sensors. This digital throttling valve is a critical component in achieving accurate LOX mass aboard the LRB. Additional hardware interface modules (HIM) for instrumentation and electrical control will be required for the LOX loading system.

Three rocket fuels are under consideration at this time for use in the LRB. They are RP-1, Methane, and Liquid Hydrogen, and are discussed separately below.

LC-39 does not have an operating RP-1 system, although there are some remnants of systems that were used to service the Saturn V vehicle at each Pad. Pad A has three dirt covered stainless steel lined RP-1 tanks that appear in good condition. Each tank has a rated capacity of 86,000 gallons. Both Pads have the remains of RP-1 pump houses, about 1400 feet of eight inch stainless steel cross country transfer line in place, and base structures for pumps and equipment. Major renovation will be required if RP-1 is selected as the LRB fuel.
The Pad A tanks have a large excess capacity over the needs of the LRB's. The third tank could be moved to Pad B or can serve as surge storage for economical purchases, or unforeseen availabiity problems. Pad B will require new storage capability. Both Pads must have pumps with motors and controllers, storage area controls, valves, plumbing, filters, purge system, and de-waterers. An off loading area with manifolds for fuel transfer from delivery tankers will be required.
Two 2000 gpm pumps (one pump redundant) will transfer the fuel through an eight inch line some 1400 feet to the MLP interface connection. A new tower to allow the RP-1 line to mate with the MLP RP-1 system will be required. Two RP-1 valve skids are needed to support the loading of two LRB's, and lift-off propellant servicing masts are planned for each LRB servicing requirement to minimize complexity and costs. Control will be based on time and feedback from LRB liquid level point sensors.

A new LPS console and additional hardware interface modules (HIM) will be required for the RP-1 loading system.

The LC-39 Complex does not have and has not had any liquid methane (LCH4) facilities or equipment. This is a new propellant fuel to this complex and will require new construction equipment.

A new storage facility could be located near the existing liquid hydrogen storage facility. A 500,000 gallon insulated storage tank should be adequate to permit some future LRB system growth. A vaporizer will assure proper pump inlet pressure and as LCH4 is a very light liquid, the fuel can be pressure transferred at slow flow rates. A location and facility for transferring the fuel from delivery tankers, a storage tank and vent system, and a flare stack for vapor disposal are some of the system elements required. A storage area control system with the necessary valves, sensors, filters, and plumbing are needed. To supply LCH4 to the Pad, two 5000 gpm pumps (one pump redundant) can be used to transfer the fuel through an eight inch VJ line some 1500 feet to the MLP interface connection.

A new tower to allow the LCH4 line to mate with the MLP LCH4 system will be required if room cannot be found on the present LH2 interface tower.

An additional tower will be required on the east side of the MLP to support a gaseous methane (GCH4) vent arm to assure that hazardous GCH4 is not released and that there are no ice formations adjacent to cold gas vents on the LRB's. The western LRB vent can be reached by an arm from the FSS. Vent lines from this tower and the FSS will be required to a new flare stack.

Two LCH4 valve skids are needed on the MLP to support the loading of two LRB's and lift-off propellant servicing masts are planned for each service point to minimize complexity and costs. Control will be based on time and feedback from LRB liquid level point sensors. A digital throttling valve is a critical requirement in achieving accurate LCH4 mass aboard the LRB.

A new LPS console and additional hardware interface modules (HIM) will be required for the LCH4 loading system.

The LC-39 Pads each have an 850,000 gallon liquid hydrogen (LH2) storage tank, LH2 vaporizer, and almost 1500 feet of ten inch vacuum jacketed (VJ) transfer line that interfaces with the MLP LH2 plumbing. The Shuttle presently utilizes the facilities that were acquired and used by the Saturn V Program.

The present LH2 storage is marginal for adequately supplying the additional requirements of the LRB's and could not support any significant growth. A 250,000 gallon storage tank with an LH2 vaporizer can be added adjacent to the existing storage dewar. The new storage tank will be connected to the ten inch transfer line at the storage area to allow the two tanks to function as a single supply. Cross connecting the vaporizers will increase reliability without increasing costs. The maximum vent rate from the LH2 storage will not be increased significantly; therefore, the new facility vent can be tied into the present storage vent line and flare stack. Valves and controls will be added to allow the storage area to serve as a unified LH2 supply system while giving maximum flexibility for maintenance and operations.

The present ten inch VJ transfer line can support the orbiter/ET and the LRB's with no or minimal impact to the present NSTS LH2 loading time. The ten inch line has supported a flow rate of more than 11,000 gpm.

A tower will be required off of the east side of the MLP to support a gaseous hydrogen (GH2) vent arm that will be needed to assure hazardous GH2 is not released and there are no ice formations adjacent to cold gas vents on the LRB's. The western LRB vent can be reached by an arm from the FSS.

The present back pressure on the ET GH2 vent is critical; therefore, an added GH2 vent line from the FSS and from the new Pad east tower to a new flare stack will probably be required.

Two LH2 valve skids are needed to support the loading of two LRB's; a "tee" from the orbiter/ET LH2 line on board the MLP will supply these two valve skids; lift-off propellant servicing masts (one for each propellant per LRB) are desired to minimize complexity and costs; a GH2 vent arm will be required to each LRB, and propellant flow to each service mast will be modulated by a throttling valve controlled by the LPS. The control will be based on time and feedback from LRB liquid level point sensors. This digital throttling valve is a critical component in achieving accurate LH2 mass aboard the LRB.

A new LPS console and additional hardware interface modules (HIM) will be required for the LH2 loading system.

Once a decision is made to select one of the three fuels, design parameters and specifications can be developed, and the acquisition and transition to the selected system can proceed. Traditional and proven NASA design review procedures will be used, and KSC-DE-512-SM will be used for guidance during the acquisition process.

3.2.4.2 Fixed Service Structure Swing Arms and Vents - The Fixed Service Structures (FSS) on both Pads A and B are configured to support the STS with the solid rocket boosters. Neither the position of the Orbiter nor the ET relative to the FSS will be affected by the introduction of the LRB's. The Rotating Service Structure, Orbiter Weather Protection System, and the Payload Ground Handling Mechanism will not be affected by phasing in the LRB's.

The increase in size of the boosters will impact the FSS configuration dependent upon the final configuration selected. Increased booster diameter will require modification to the ET gaseous hydrogen vent arm. The larger boosters will be able to more safely clear the FSS if the ET vent connection were rotated toward the north as positioned on the pad. The increased length of the Liquid Hydrogen and Liquid Methane boosters will require additional modifications to the ET gaseous oxygen vent arm.

As discussed earlier, the Orbiter Thermal Protection System must be protected from the impact of ice. Therefore, methods for control or prevention of ice are mandatory. Vent arms are simple controls for cold gaseous boil-off from LH2 and LCH4 to prevent ice formation. Other methods of ice control look promising for eliminating the hazard of ice from LOX boil-off.

The detailed design requirements for the ET vent arms modifications will be developed first. They will be closely followed by the detailed requirements for the new vent arms for the boosters. Planning calls for the new booster vent arms to be mounted on the FSS (west side) and on a new tower to be constructed on the east side of the pad using a similar design to the FSS with proven components.

The vent arms are critical for safety. All normal design, reliability, safety and logistics reviews will be performed. Development, acceptance, and qualification testing will take place at the Launch Equipment Test Facility (LETF) for the modified ET vent arm and for the new booster vent arms. After successfully passing the tests at the LETF, the vent arms will be installed on the towers at the pad. Lines will be installed to conduct hazardous vapors to the new flare stacks. The "Pathfinder" will permit integrated validation at the pad after completion of sub-system checks.

Scheduling the installation of the arms at the pad should present no major conflicts as a single pad can come very close to supporting the maximum anticipated SRB/STS launch rate.

3.2.4.3 Support Equipment - The pad support equipment presently dedicated to the SRB operation will be reviewed for potential use in servicing or checking out the LRB's. If present equipment can be adapted or modified for LRB use, this approach will be pursued prior to developing or acquiring new support equipment.

Although detailed requirements can not be identified at this time, access and service to many components of the LRB will be required while the vehicle is at the pad (ie; electronics, sensors, valves, the LRB rocket engines, and engine actuators). Support equipment will be required for these functions.

The extensible columns used to support and stiffen the MLP near the LRB support and holddown area will be sizable and hard to handle. A large fork-lift will have to be modified to place and remove these columns under the MLP (as was the Saturn V extensible column handler).
As the depth of definition and designs proceed, support equipment will be identified and normal acquisition steps will be followed.

3.2.5 Launch Control Center (LCC) Modifications - The Launch Control Center will require additional hardware and software for monitoring and controlling the LRB's. The existing SRB hardware and software will have to be retained in the LCS until SRB's are no longer utilized by the NSTS. Modifications to the facility should be minimal, primarily those needed to install extra consoles and racks to accommodate added software and dual flow management.

3.2.5.1 Launch Processing System (LPS) - The planned up-grade of the launch processing system should include the capability to handle the requirements of both SRB's and LRB's in flow. During the early stages of the LRB design program, LPS requirements will be developed by GDSS and provided to MSFC. With NASA coordinating both programs, an orderly transition of LRB requirements into the up-graded LPS will have minimum cost impact. The integration of LRB's into the existing LPS system will require a detailed study of the existing system.

3.2.5.2 Software Development - Additional software will be required for control and monitoring of the new and modified ground support systems and equipment. New software will also be required to monitor and control the LRB prelaunch processing on the pad. GDSS will provide the requirements and parameters for developing the LPS software for the LRB's.

3.2.5.3 Dual Flow Management - The introduction of LRB's will take place while SRB's are in flow. This will require that the launch control center have the capability to dedicate both console and software processing to SRB's and LRB's. During the early stages of design, GDSS will identify the LRB requirements for monitoring and control. Through a GDSS/MSFC/KSC team effort, dual flow management problems will be resolved, and appropriate OMI's will be prepared.

3.3 Ground Support Equipment (GSE) Acquisition - KSC has a history of competently designing and acquiring ground support equipment for its space programs. Examples of past acquisitions are the Multi-Mission Support Equipment (MMSE) transporter, cargo canister, strongback, payload environmental transport system (PETS), ET transporter, Shuttle/MLP crawler-transporter, and numerous others (ie; cranes, slings, dollies, vehicles of all types, and SRB retrieval systems).

From this experience base, any new GSE needed for the LRB program can be designed and procured. NASA and DOD procurement regulations and FAR's will be followed in the procurement process. KSC-DE-512-SM and KHB 1200.1A will be used as guidance for the design, acceptance, test, verification, and validation during the transition program.

3.3.1 LRB Transporter - If it is determined that a new ground transporter is needed for the LRB at its manufacturing site, the design should take into account the LRB handling and movement requirements at the launch site, thus allowing NASA to realize savings by multiple procurement. In the event that the ET transporter can be modified to move the LRB and maintain the capability to move the ET, this alternative will be pursued during this transition program.

3.3.2 Lifting and Rotation Devices - It will be necessary to design and acquire slings, a strongback, or attachment brackets to handle the LRB during loading onto and unloading from the barge, during rotation and movement in the VAB, and during mating with the ET and orbiter on the MLP. If this same type equipment is designed and used at the manufacturing site, duplicate items will be procured for use at the launch site. If KSC-unique items are needed, they will be designed at KSC and acquired using KSC procedures.

3.3.3 Special Test Equipment and Tools - At some point in time during the LRB DDT&E program and transition at the KSC launch site, a requirement will develop for special tools and test equipment although it is too early in the program to do it now. When such items are identified, KSC or MFSC, as appropriate, will initiate the necessary acquisition process to assure that support is in place when required.

3.4 Operations Support and Logistics - Logistics Planning and Engineering, Product Support requirements, and Operations Support necessary for the LRB development program are essential to an orderly transition. Government, contractor, and sub-contractor personnel who are involved in the LRB program management, planning, concept and/or specification development, design, manufacture, assembly, checkout, verification, launch operations, maintenance and supply support, training, facilities, transportation, and ground support equipment (GSE) are also indirectly or directly involved in logistics and operations. The logistics program will be driven to some degree by the design, manufacture, transportation, storage, assembly, checkout, and operations concepts which evolve from program management decisions, and by directed program milestones. Figure 3-4 depicts the relationship of logistics and support requirements to major LRB program milestones.

LRB LOGISTICS SUPPORT SCHEDULE (PRELIMINARY)

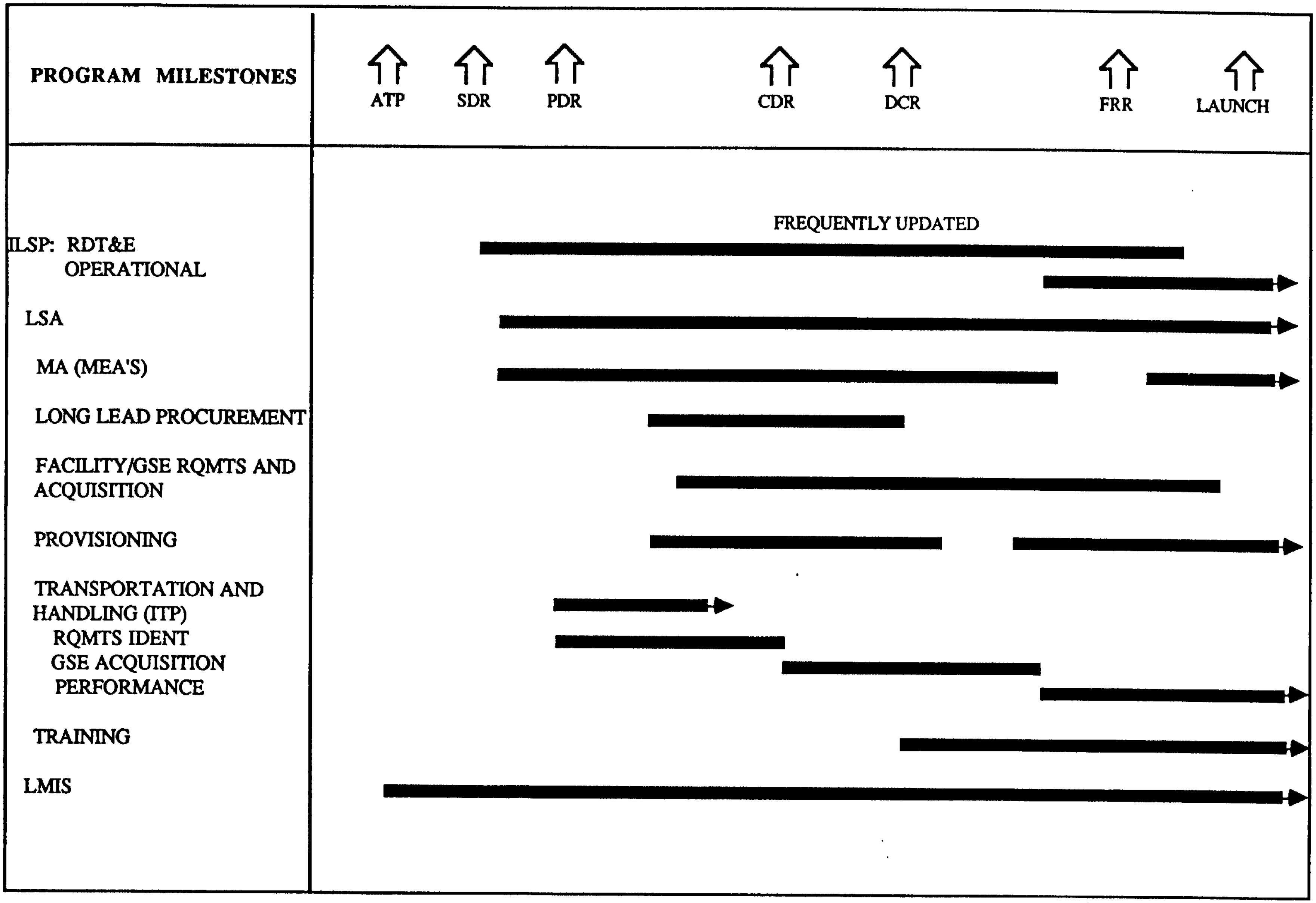


FIGURE 3-4

3.4.1 KSC Manpower Impact - It will be necessary to increase the contractor work force at KSC to prepare LRB processing and launch facilities and to accommodate the requirements of the transition and flight test programs. Additional NASA contract administration and surveillance personnel may be required at KSC in addition to any MFSC personnel who may be temporarily located at KSC during transition. With the addition of manpower, the requirement exists for the added office space, housing, transportation, and other routine support that accompany increases in personnel strength. Planning for these accommodations must take place at a very early date since personnel increases must usually be in place before other work begins.

3.4.1.1 Training and Certification of Personnel - One of the principal impacts on personnel will be the extensive training and certification required to assure a quality work force ready to process and launch the new LRB space vehicle. This task is an important part of the Integrated Logistics Support Program, and it is implemented by NASA and NASA contractors as part of all new systems acquisitions. Training will consist of both formal and informal courses, on the job training (OJT) and testing for compliance and certification.

3.4.1.2 Dual Flow Manloading - One of the NASA goals is to transition the LRB system while maintaining the planned shuttle launch program. To accomplish this objective will require that a dual processing flow be established, and that added manpower be integrated to support it. Some people will be required to work on both the SRB and the LRB programs once the vehicles are rotated for stacking in the VAB. This may require that special OMI's be devised and that additional supervisors and quality control people are in place to maintain the required safety and quality standards. During the prelaunch and liftoff activities on the launch pad, exceptional care must be taken to assure that use of OMI's and LPS software are properly supervised.

3.4.2 Documentation Development and Verification - LRB program documentation will be developed and maintained in accordance with the requirements of JSC 07700 Directives and other pertinent NASA issuances. Technical documentation pertaining to KSC facilities and equipment shall be provided as specified in the NASA LRB acquisition contracts, and shall be written, verified, and published in accordance with DOD-D-1000, KSC-DE-512-SM, KHB 1200.1A, and KMI 8610.11. Vendor data, such as maintenance manuals will be used to the maximum extent possible. Special requirements and specifications having an impact on maintainability shall be documented and furnished to the O&M agency having responsibility for development of OMI's.

3.4.3 The Integrated Logistics Support System - Decisions made during the development program will have a lasting effect on the configuration of the LRB and on its operations and support infrastructure which will impact cost, availability, and utilization for the life cycle of the program. The part of total program costs that often has reduced visibility during hardware development can be identified with the operational and logistics support costs which accumulate over the life of the hardware and during the employment of the system. Effective program management control of life cycle costs begins with the concept, planning, and design phases of a DDT&E program. Active interface between logistics support personnel and the planners, designers, engineers, and manufacturers is necessary during system design to assure economical production, supportability, maintainability, and availability of the operational system. This philosophy will be followed during the DDT&E and operational life of the LRB system. It is the genesis of an integrated logistics support program.

One cost control concept to be used on this program is to make use of existing facilities, whenever and wherever possible, if they can reasonably be adapted or modified to fit requirements. Integration with the Shuttle Processing Contractor operations and support systems early in the DDT&E program should result in a shorter learning curve and further cost savings.

3.4.3.1 Logistics Engineering and Logistics Support Analyses (LSA) - The processes by which the essential interface between logistics personnel and designers can be coordinated are included in the LSA. Maintenance Engineering Analyses (MEA's) of preliminary designs, and participation in all design reviews by logistics personnel will help assure the acquisition of hardware that is economically supportable. Early consultation between design engineers and logistics support personnel will also assist in timely procurement of long lead-time of hardware.

Considering the complexity of the LRB program, it is essential that an Integrated Logistics Support Plan (ILSP) be developed. Such a plan will facilitate the coordination of engineering, design, and support functions during the LRB development program and during transition and turnover to the operational program. The elements of the system will be categorized into a work breakdown structure (WBS) for use by all design, production, operations, and support functions to assure the proper allocation of resources and to assist in implementation of the ILSP. MIL-STD-881 provides guidance for development of WBS. The ILSP is a dynamic document which begins with broad objective-oriented concepts and becomes more specific as a task and milestone oriented document as the transition program develops. It must be frequently up-dated in response to new management directives and activity feedback to be useful as a "working document" and to assist in orderly transition. The ILSP will become a working document as soon as hardware configuration becomes viable (usually at the preliminary design review) and will address the following subjects and be formatted approximately as follows:

a. System Description

b. Program Management

c. Applicable Documents

d. Operations Concept (Including Processing Flow)

e. Maintenance Concept

f. Acquisition Strategy and Procurement Approach

g. Test and Evaluation Concept

h. New Technology Impact

i. STS Interface Impact

j. Operational Logistics Support Concept

k. Milestone Schedule Charts for each Program Element and LSA Task

l. Manpower and Personnel Requirements

m. Configuration Management System

n. Logistics Management Information System

o. Logistics Management Responsibility Transfer (LMRT) Concept

p. Sustaining Engineering Concept

q. Integrated Supply Support Plan (ISSP)

r. Logistics Support Analysis (LSA) using MIL-STD-1388-1 and 1388-2 guidance to include interfaces with the following tasks, as applicable:

1. System/Equipment Design Program
2. Reliability Program
3. Maintainability Program
4. Human Engineering Program
5. Standardization Program
6. Parts Control Program
7. System Safety Program
8. Packaging, Handling, Storage, and Transportability Program
9. Initial Provisioning Program
10. System/Equipment Testability Program
11. Survivability Program
12. Technical Publications and Documentation Program
13. Personnel Training and Certification, and Training Programs
14. Facilities Program

Logistics planning and support guidance is provided in a wide range of policy directives and management instructions. Some which apply are listed below:

NHB 4100.1 - NASA Materials Inventory Management Manual

NHB 6000.1B - Requirements for Packaging, Handling, and Transportation for Aeronautical and Space System, Equipment and Associated Components.

MSFC HDBK-527A - Material Selection Guide.

JSC 07700, Volume XII - Space Shuttle Program Integrated Logistics Requirements (latest Revision, including referenced applicable documents.)

JSC 08151 - Space Shuttle Program Maintenance Baseline Requirements.

JSC-SE-S-0073 - Space Shuttle Fluids, Procurement and use Control.

DOD-D-1000 - Drawing, Engineering and Associated Lists, Specification for

DOD4100.38-M - Provisioning and Preprocurement Screening Handbook.

AF Regulation 800-8 Acquisition Management-Integrated Logistics Support (ILS) Program.

MIL-D-9024 - Packaging, Handling, and Transportability in System Acquisition Items.

MIL-HDBK-217 - Reliability Prediction of Electronic Equipment.

MIL-HDBK-472 - Maintainability Prediction.

MIL-STD-470A - Maintainability Program for Systems and Equipment.

MIL-STD-480 - Configuration Control - Engineering Changes, Deviations and Waivers.

MIL-STD-721 - Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety.

MIL-STD-794 - Packaging

MIL-STD-881 - Work Breakdown Structure for Defense Material Items.

MIL-STD-975-NASA Standard Electrical, Electronic, and Electromechanical (EEE) parts list.

MIL-STD-1366 - Packaging, Handling, Storage, and Transportation Systems Dimensional Constraints, Definition of.

MIL-STD-1367 - Packaging, Handling, Storage, and Transportation Program Requirements.

MIL-STD-1369(EC) - Integrated Logistic Support Program Requirements.

MIL-STD-1375 - Provisioning, Initial Support, General Requirements for.

MIL-STD-1379 - Contract Training Programs.

MIL-STD-1388-1 - Logistic Support Analysis.

MIL-STD-1388-2 - Logistic Support Analysis Data Element Definitions.

MIL-STD-1552 - Provisioning Technical Documentation, Uniform DOD Requirements for.

MIL-STD-1561 - Provisioning Procedures, Uniform DOD Requirements for.

KHB 1200.1A - Management of Facilities, Systems, and Equipment Handbook.

KHB 3410.1 - Implementing Instructions for KSC Systems, Safety and Skills Training and for Certification of Personnel.

KHB 4000.1 - Kennedy Space Center Supply Manual.

KHB 5310.1 - Government - Industry Data Exchange Program and Alert System.

KHB 5310.11 - Nonconformance/Problem Reporting and Corrective Action System

KMI 8610.11 - Distribution of Operations and Maintenance Instructions

K-SMO-12.01 - Kennedy Space Center Operational Logistics Plan.

K-STSM-12.5.04 - Ground Operations Training Plan for STS Operations.

KSC-DE-512-SM - Guide for Design Engineering of Ground Support Equipment and Facilities for use at Kennedy Space Center (Including referenced documents).

Some of the more important elements of logistics support which must be considered early in the DDT&E program are discussed in the following subparagraphs.

3.4.3.2 Logistics Management Information System (LMIS) - The LMIS includes all information generated for or used by logistics managers in managing existing LRB program resources or in acquiring or supporting others. It can be used by both NASA and contractor managers. Its baseline is the LRB program ILSP and transition ILSP as modified to keep up with progress and program changes. The WBS, which encompasses the entire LRB program plus pertinent management directives and schedules will be the framework upon which it is structured.

The basic required elements of the Logistics Management Information System (LMIS) are data on cost, schedule, and performance applied to the various functional tasks as broken down in the LSA. Management must have information upon which to base decisions on design changes, tracking of program milestones, budgetary inputs, other program interfaces, trade study results, and various program support problems.

An efficient Configuration Management System is essential to a useful LMIS. Program Management must tie the two together to save both time and resources. Existing in-house contractor information systems plus those at KSC should provide necessary data to support management reviews, a performance measurement system, procurement, inventory control, maintenance, safety requirements, and schedule tracking. They can be augmented by a PERT/TIME type system if management determines that one is needed. At KSC, the selected contractors should make maximum use of the KSC systems and procedures. The KSC Inventory Management System (KIMS), Maintenance Management and Control System (MMACS), the KSC Data Management System (KDMS), the Problem Reporting and Corrective Action System (PRACA), and the Government-Industry Data Exchange Program (GIDEP) Alert System will be used for management support. A "Red Flag" system will be established to highlight urgent problems.

Manpower needed to operate existing systems in support of management requirements for information, and to prepare for and support review activities, should be programmed.

Data requirements schedules will be established to support program milestones. These requirements will appear very early in the program and will continue through DDT&E and into the operational lifetime of the system. See Figure 3-4.

3.4.3.3 Maintailability Analysis - This analysis is a compendium of individual maintainability engineering analyses (MEA) of every element, component, or part of the LRB and its launch support systems. It will be performed early in and concurrent with the design process, and is dependent on inputs from both designers and logistics/maintenance personnel. When properly performed, it will help determine the detailed design approach, and will influence system costs, schedules, facilities, and performance. It is led by the system maintenance concept, but also serves as feedback data to influence changes in that concept. It precedes final design acceptance. Following are some of the factors to be considered in performing the maintainability analysis:

a. System reliability criteria (FMEA's, Mission and Operations profile, critical items lists)

b. Modeling requirements (for quantitative estimates and allocations of time to repair, design specification impact, cost of acquisition, and life cycle cost.)

c. The allocation process as it relates to specific subsystem or component preventive and corrective maintenance requirements. This top down process is a technique of budgeting maintenance tasks among various items of a system to meet established maintenance goals. It will be iteratively updated to reflect refinements and changes during design evolution, and to insure consistency with the design specifications.

d. Predictions of the ability of the system, subsystem, or equipment to achieve maintainability requirements for each level of maintenance specified. Values are based on criteria such as mean time between failure (MTBF), mean time to repair (MTTR), fault isolation, false alarm rates, tests (using built-in or external test equipment), times to disassemble, interchange, reassemble, align and checkout. Also considered will be system physical and functional data, parts and labor costs, design tradeoffs, and time measurement methodology. The predictions are normally accomplished using a hierarchial structure of predetermined standards based on the time measurement system (MTM) references in NHB 5300.4 (IE) Appendix E. and guidance for predicting maintainability times in MIL-HDBK-472. They are to be used in maintenance planning and provisioning of spares.

e. The testability of systems, subsystems, or parts based on design criteria and characteristics identified to effectively detect, locate, and isolate faults to a specified level of maintenance. The latest available built-in test equipment (BITE) and checkout and alignment systems should be included to minimize maintenance and checkout costs.

f. Verification of maintainability of the subsystem design in accordance with established criteria. This is accomplished by analysis, assessment, test, demonstration, or combinations thereof.

g. Availability of maintenance capability (ie; shops, tools, personnel skills, contractor support) and supply support. Existing KSC facilities, resources, and procedures will be used to the maximum extent possible.

Maintainability analyses will be the responsibility of the design organization with active participation by maintenance and logistics personnel before and during all design reviews. These maintainability requirements data will be developed as early as feasible in the design evolution so that maximum benefit to design drawings and specifications can be realized. Appropriate Standards, Specifications, Handbooks, and Directives from both Government and Industry will be consulted by designers and logistics personnel for detailed guidance during the design cycle. Many are listed in Section II of KSC-DE-512-SM. In addition, Sections VII and VIII of KSC-DE-512-SM provide expanded guidance for actions essential to the design tasks and initial provisioning of spares, ground support equipment and facilities. Much of the information in this publication is also relevant to the design of the flight article hardware of the LRB system. As soon as long lead time parts are firmly identified, logistics engineering personnel will initiate procurement action in support of the fabrication process.

Appropriate allocation of manpower from the design and logistics organizations will be made within the scope of contracts and program management guidelines, as soon as needed to accomplish the design and logistics tasks, including the maintainability analysis. When maintainability analysis reveals the need for procurement of parts or acquisition of tools, GSE, or facilities the logistics personnel will help develop budgeting and programming actions as necessary within management guidelines.

Schedules for logistics and maintainability analysis actions will be developed as necessary to conform to master program management schedules. Figure 3-4 shows the relationship of the Maintainability Analysis (MA) to master program milestones.

3.4.3.4 Provisioning and Procurement - Provisioning activities during the DDT&E and transition programs will be limited to the acquisition of hardware and spare parts needed for prototype and design proofing, and program test activities. The scope of the test program will influence the magnitude of provisioning and procurement of spares during transition and prior to logistics management responsibility turnover (LMRT). As systems designs reach baseline configuration the prime contractor will develop provisioning technical documentation for delivery to NASA, will assist NASA in long lead time item identification, initial operational spares requirements and the development of life cycle cost estimates for program budgetary cycles.

Initial and follow-on spares provisioning criteria and technical documentation are based on products of the LSA. Requirements include hardware identification/costing, indentured parts lists, fuel and fluids requirements quantification, support and test equipment identification, and types/quantities of pressurants needed. Lists will be compatible with the planned levels of maintenance, and distribution of assets after their acquisition. Common hardware (ie; commercial off-the-shelf or available from government sources) will be identified as direct procurement candidates. Detailed provisioning data elements are described in JSC-07700, Volume XII, Table 5.1, and will be used as guidance in conjunction with formats recommended by MIL-STD-1388-1 and 2.

A supply support concept will be developed based on contract stipulations, resource limitations, maintenance concepts, and DDT&E program objectives and management direction. LSA data sheets will be reviewed at provisioning conferences by supply, maintenance, and engineering design personnel to determine quantities of spares needed to support the DDT&E program. After design baseline, additional provisioning conferences will be conducted to develop recommendations for initial operational spares stockage. When design changes occur after spares have been purchased, inventory control and stock rotation procedures will be established to assure modification or retrofit of all spares which can be economically upgraded. In addition to developing provisioning technical documentation, the prime contractor will develop O&M documentation to support repair of reparable items and to facilitate the retrofit of spares in stock. Design change impact to O&M documentation will be an iterative process so that when the LRB system and its facility support infrastructure reaches operational status and LMRT, current usable O&M documents will be available for delivery to NASA. Once a baseline configuration is reached design drawings and O&M documentation will be placed under configuration control. Active coordination with and participation by the KSC SPC and BOC will be implemented to assure complete compatibility with the SPC O&M procedures and activities during transition.

Manpower and money are the elements needed to accomplish the provisioning tasks. Procurement of provisioned items will be as provided for in program management directives, budgets, and contracts.

Schedules will conform to program milestones as shown on Figure 3-4.

3.4.3.5 Transportation and Handling - The manufacturing concept and location, the storage and holding sites, and the processing and checkout flow will determine the magnitude of the transportation and handling tasks for the LRB and its support systems. Pending development of these concepts and relevant management decisions, the scope of this requirement will be limited to the movement of the LRB from the barge site to launch processing site, such handling as is necessary for movement and processing of LRB elements, and the miscellaneous transport needs which will be provided at KSC through the STS Transportation Control Center using NASA or GSA resources.

The existing excellent transportation system at KSC will be used for generalized support, and the KSC Transportation Coordination Center will serve as a focal point to fulfill requirements and maintain status of all material movements to and from KSC. The GSA Interagency Motor Pool at KSC will be used to the maximum degree possible. Movement and lifting of the LRB and major support equipment will be accomplished to the maximum degree possible by using the STS external tank transportation and logistic support system, or a similar concept. Use of the Navy Trident Basin crane will be considered for barge unloading.

An Integrated Transportation Plan (ITP) will be developed to tie together the concepts, requirements, and resources to assure the efficient transportation and handling support to the LRB DDT&E program, launch site transition, and the follow-on operational program.

In order to satisfy the LRB transportation and handling requirements, program management decisions must be made early to establish the manufacture, storage, and transportation concepts. The facility and equipment support needed must be identified and NASA must plan for the acquisition of any items which cannot be obtained from within existing KSC or MSFC resources. Manpower, equipment, and dollar resource requirements will depend on the scope and content of the ITP. Figure 3-4 illustrates the relationship of these requirements to program progress.

3.4.3.6 Training - Initial and refresher training and certification will be limited to personnel whose duties do not directly involve flight operations. Contractor or subcontractor personnel who have preflight processing, logistics, or maintenance jobs will receive training as determined by the established operations, maintenance, and supply concepts, and as directed by NASA.

New designs or acquisition of new hardware, or modifications to existing systems and equipment dictate that people involved in the maintenance and support of such new items or systems receive training and be certified as competent prior to working with them. These training requirements are identified as a result of the maintainability analysis and the LSA. Design engineering personnel will assist in defining the training requirements for new hardware systems which they design, and providing operations and maintenance requirements specifications (OMRSD's) to support O&M documentation and personnel training.

As new requirements are identified, logistics support organizations will establish new training programs and schedule personnel to receive training in the new skills required and to be certified as competent. In-house training procedures for contractor offsite training, and for safety and skills training at KSC will take guidance from K-STSM-12.5.04, "Ground Operations Training Plan for STS Operations" and from KHB 3410.1, "Implementing Instructions for KSC Systems Safety and Skills Training and for Certification of Personnel".

Training resources available at KSC will be used to the maximum extent possible for training of people located at the launch site.

Training schedules will be developed to support new hardware acquisition schedules and other LRB program milestones. Figure 3-4 shows the approximate time when training becomes a major factor in program support.

4.0 VERIFICATION AND VALIDATION

Acquisition of new facilities and equipment and modifications to the VAB high bays, the MLP's and the launch pads will require verification and validation by inspections, tests, and demonstrations. A schedule will be developed for the KSC modifications to identify those verifications and validations that can be performed with minimum impact on the scheduled SRB flights. Typically, the critical events are cold flow tests, pathfinder tests, tanking tests, operational readiness inspection, and flight readiness firing.

4.1 Cold Flow Tests - The propellant system modifications at the launch pad include new/modified fuel storage and transfer systems. This test will ensure design specifications have been met, the integrity of the systems is verified and the system meets the operability requirements. The cold flow test will utilize the launch processing system demonstrating its ability to control and monitor the flow of the propellants. These tests will be similar to cold flow tests used on other rockets that KSC personnel are familiar with.

4.2 Pathfinder Tests - Two test-LRB's will be utilized as pathfinders to check mating clearances, and mechanical, electrical, and fluid hookups. The test in the VAB will check handling of the LRB's, mating with the ET and orbiter on the MLP, clearances of the work platforms, and other fit, form and function requirements.

The pathfinder test at the launch pad will check mating and clearances with the RSS, FSS, proposed additional towers, swing arms, electrical systems, mechanical systems, fluid systems and the launch processing system. The pathfinder tests are similar to pathfinder tests conducted by KSC for the NSTS.

4.3 Tanking Tests - The external tank and the LRB's will be filled under the same conditions as an actual launch. This will demonstrate the operational readiness of the propellant fuel systems, the launch processing system and the operations personnel.

4.4 Operational Readiness Inspection - This inspection is similar to NSTS inspections conducted by KSC. The LRB's will not introduce any major change to this inspection process. GDSS will provide inputs to the current operational readiness inspection documents and be available to assist in the actual inspection. System documentation will be provided in a form that shows the entire system with all components clearly identified to aid in this inspection.

4.5 Flight Readiness Firing - This operational test will demonstrate that the NSTS with LRB boosters is ready for flight. GDSS will work with the KSC SPC to prepare a procedure with recommended sensing devices and parameters to be monitored during this test. The results of the tests will be reviewed by GDSS for any discrepancies from design parameters, and the results of the analyses will be provided to MSFC.

APPENDIX 4

AUTOMATED MANAGEMENT AND OPERATIONS PLAN

SECTION 1
INTRODUCTION

Recent advances in automated technologies have necessitated investigation their augmenting, and in some cases replacing, current systems. Incorporation of many of these technologies into existing programs for reasons of cost, quality, or reliability suggests that these technologies may be applicable to the LRB. The following plan will examine several new and available technologies that could become a part of the overall LRB program.

1.1 OBJECTIVE AND APPROACH

The objective of this plan is to determine what forms of automation and robotics are available and applicable to the LRB program. The approach will be to select areas within the program that seem to have potential for the use of advanced automation and robotic technology and to apply some selection criteria to determine if the use of these technologies would be beneficial. The plan will also identify possible strategies for implementation of these technologies in the selected areas.

1.2 AREAS OF APPLICATION

Figure 1.2-1 depicts the three general areas of the LRB program as DDT&E, Production, and Operations. Within these three areas, several opportunities for advanced automation and robotics have been selected based on industry as well as other programs within NASA.

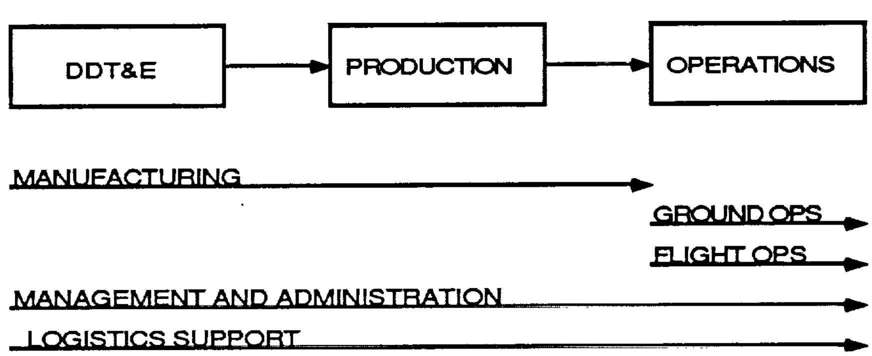


Figure 1.2-1. Areas of Application and Their Relationship to Program Phases

These target areas for new technology incorporation are manufacturing, management and administration, logistics support, design, ground operations, and flight operations. Table 1.2-1 shows suitable applications for automation found within each target area.

Table 1.2-1. Automation Candidates For Target Areas.

DESIGN
- DFM/DFA Analyses
- CAD/CAM
- CAE
- Scheduling

MANUFACTURING
- Configuration Management
- Methods and Standards
- Scheduling, Planning & Procurement
- Tooling
- Assembly and Fabrication
- Overhall/Rebuild
- Quality Control
- Budgets

GROUND OPERATIONS
- Work Stations
- Work Instructions
- Spares/Parts Provisioning
- Fault Detection and Isolation
- Robotics
- Real-Time Status Reporting
- Scheduling
- Launch Operations

LOGISTICS SUPPORT
- Inventory Control
- Procurement
- Retrieval
- Shipping and Receiving
- Consumeables/Expendables

FLIGHT OPERATIONS
- Scheduling & Planning
- MCC Reconfiguration
- Flight Monitoring
- Problem Assessment
- Data Load Preparation
- Feasiblity Analysis and Payload Manifesting
- In-Flight Fault Detection and Isolation
- Payload/Vehicle/ Tracking/Status

MANAGEMENT AND ADMINISTRATION
- Centralized Program Control
- Problem Assessment
- Launch and Flight Operations
- Monitoring
- Real-Time Status for Decision Making
- Scheduling and Planning
- DBMS for Analysis and Study
- Security
- Cost Control
- Configuration Control
- Documentation Production
- Information Dissemination
- Manpower Utilization

This scenario adheres to the basic CIM (Computer Integrated Manufacturing) philosophy of providing information systems to support the integration of applicable areas within the program so that the program operates as a single integrated system instead of autonomous groups, production areas, or units. A survey by the National Research Council discovered the following gains when elements of CIM were implemented:

- Engineering design costs were reduced by a factor of 2
- Productivity increased from 40% to 70%
- Lead time was reduced from 30% to 60%
- Product yields were from 2 to 5 times higher
- Personnel costs fell by 5% to 20%

1.3 MASTER DATA BASE CONFIGURATION

To achieve this integrated system of design, production, and operations, a powerful master data base which is accessed by a highly automated and intelligent front-end user interface is needed. With the master data base and front-end expert system in place, the goal of achieving an integrated program is feasible. The master data base would be used throughout the program life and would not only serve the different elements of the program, but would also be the "corporate" memory of the program to track the design decisions, program changes, and cost changes, as well as production outputs.

The master data base as shown in Figure 1.3-1 could be either a distributed data base with various pieces of the data base strung along the "back bone" of some network or could be a single data base that is a node on some network. The complexity and scheduling for development of the LRB will dictate the hardware requirements for the given configuration, but at this point the most cost effective approach seems to be a configuration with a small to medium sized local mainframe housing the front-end expert system and functioning as a front-end to the master data base which would be a virtual entity made up of information stored on computers in various locations. There are powerful computer resources such as large mainframe computer networks and applicable Manufacturing Resource Planning (MRP II) software within General Dynamics which could be made available for the LRB program. Access to computers within NASA with applicable information could also be a possible source of data base information.

The master data base would be a central element to the automation of the LRB program. As shown in Figure 1.3-1, the master data base would be the focal point for the collection of all the data that pertains to the program. This includes data from such diverse areas as program management to operational procedures. All data and decision tools would be part of this master data base.

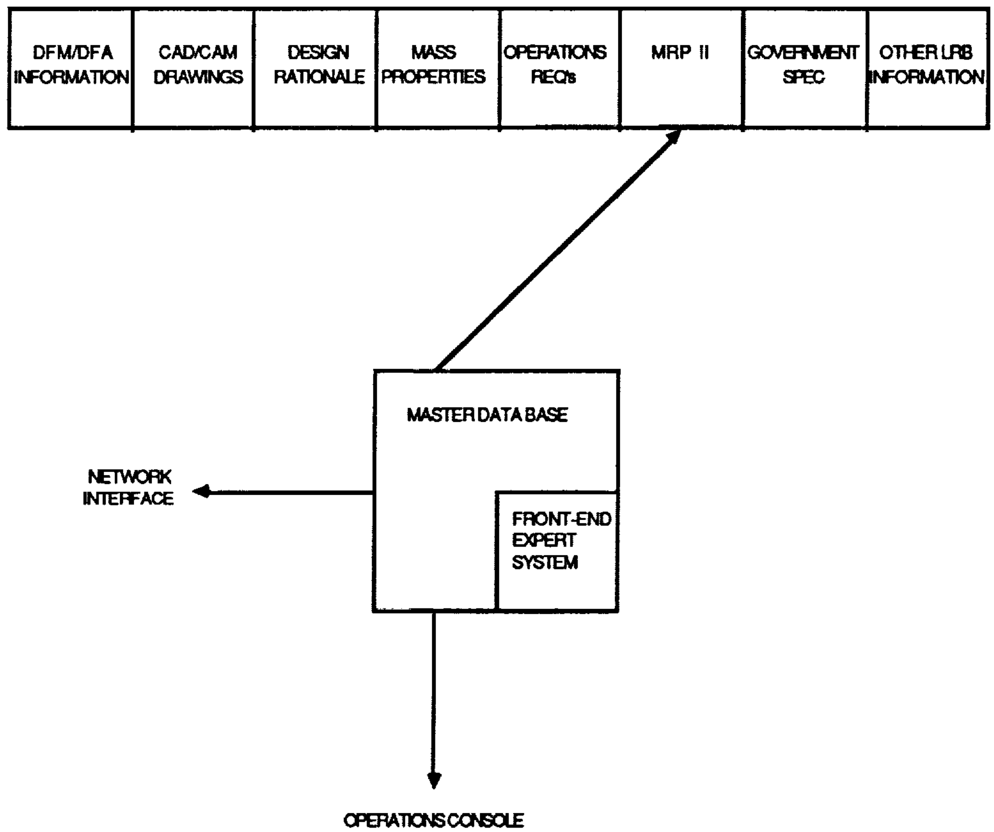


Figure 1.3-1. Master Data Base Configuration

In conjunction with the master data base the intelligent user interface would allow for manipulation of the stored information. This expert system would allow for the recombination, extraction, and interpretation of data within the master data base by those given access. These individuals or groups of individuals could be from General Dynamics and its subcontractors, NASA, or others with the "need to know" such information. Access could be controlled through passwords.

1.3.1 DESIGN KNOWLEDGE CAPTURE

Design Knowledge Capture is a preliminary and important function in the development of a truly automated program. As a portion of the front-end expert system, the design knowledge capture portion contains items such as requirements, design specifications, design rationale, cost projections, scheduling, materials listings, organizational structuring, responsibility assignments, etc.

Since the DKC system is at the heart of the automation process of the program, it is important to understand the functions of the DKC system. There are three major functions of the DKC:

1. <u>Design Knowledge Acquisition</u>
   The DKC system collects all information about the program as a whole. This includes the following:

   a. Design Rationale
   b. Design Drawings
   c. Specification Requirements (government and other)
   d. Schedules
   e. Costs
   f. Operational Considerations
   g. Safety Requirements
   h. Materials Lists
   i. Testing Requirements

2. <u>Design Knowledge Manipulation</u>
   Given the above as well as other inputs, the DKC system develops several outputs. These include the basic multi-dimensional data base matrices.

3. <u>Knowledge Synthesis</u>
   Knowledge Synthesis is a process where the DKC system is capable of developing information about the design, production, or operations of the LRB's from the information stored in the data base. Information could include, but is not limited to, the following:

   a. Operational Procedures
   b. Operational Parameters listing for Real Time operations usage.
   c. Code Generation for Fault Diagnostics

   While the incorporation of a knowledge synthesis ability into the front-end expert system is attractive, especially in the area of flight operations, its technological feasibility is a prime factor. This feasibility will be discussed in Section 5.

Designated experts in each phase of the program would help develop the DKC system by providing as much up-front essential information as possible. The DKC system/data base and expert system designers would provide standard forms for all "experts". These forms would ask each what information was needed from the data base to accomplish a certain task and what outputs would result from this task.

1.3.2 DATA BASE STRUCTURE

The structure of the master data base is based on an object-entity relationship approach. This involves the use of a frame based system for identifying and manipulating the data within the data base to allow for an almost infinite arrangement of data relationships and to allow the data to be manipulated by intelligent inference engines within the expert system. Figure 1.3-2 describes and example object/frame. The object-entity relationships as established by the front-end expert system designers would allow data base queries in a "free form" type interface, a standard user interface, and a schematic information interface allowing queries on object or system relationships within the LRB corresponding to a functional flow diagram.

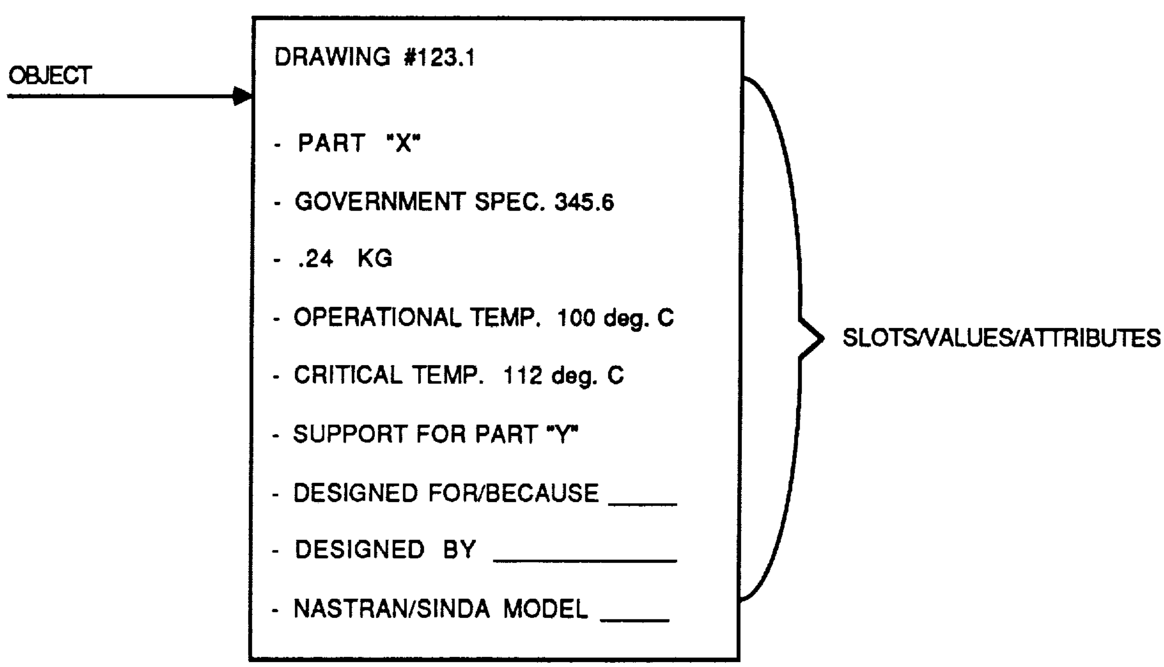


Figure 1.3-2. Frame Object

Figure 1.3-3 shows the frame structure. All information about object 1 in the data base is inherited by all following objects unless otherwise desired. This may be achieved without coding, records, fields, or files. Objects would be "children" of Part X (as referred to in Figure 1.3-2) and inheritance would provide operational flow for procedures and diagnostics in the specific area of the LRB system. Each object could occur only once but have infinite relationships with other objects, and information about each object could be connected to other objects.

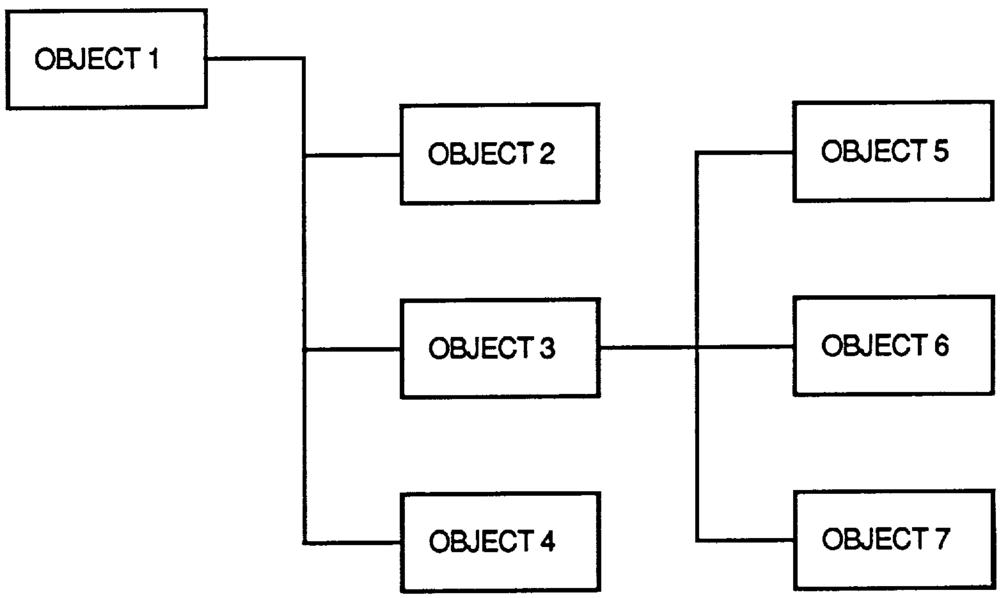


Figure 1.3-3. Frame Structure

1.4 SELECTION CRITERIA

The selection criteria for determining whether or not to implement a given automation strategy are as follows:

- Technological Risk
- Integration with STS
- Cost
- Quality/Safety

To determine the technological risk, the availability and integrity of the proposed strategy will have to be assessed given current information. The criterion of STS integration would mainly have an impact on the strategies under consideration for operations (both ground and flight) applications. Given existing knowledge, it must be determined that a given automation strategy can be phased into the current system without undue stress on present operations. The cost and potential payback of a strategy should also be considered when examining automation strategies. An automation strategy should not only be implemented because the technology exists, but should also offer cost benefits. Although cost is probably the most significant factor when considering different forms of automation, the quality and safety inherent in automated systems should also be influential in evaluating them. Automated systems can increase the quality of products and communications while eliminating many time consuming processes, and can also be used in areas where human safety is a factor.

SECTION 2
DESIGN

The design of a product must be simplified for automation and assembly in order to automate production of most parts. Simplification of product design is beneficial from a cost standpoint even if robots or hard automation prove to be too expensive for use in an area of production. Design for Manufacture (DFM) means the avoidance of features in a product component that are unnecessarily expensive to produce. To successfully adhere to DFM, Design for Assembly (DFA) must be practiced. DFA techniques primarily aim to simplify the product structure so that assembly costs are reduced. This simplification of design results not only in part and assembly cost reductions, but also in improved reliability and reduction in inventory and production-control costs. While it estimated that DFM/DFA and CAD(Computer Aided Design)/ (Computer Aided Manufacturing)CAM operations make up 10% of total recurring cost, DFM/DFA also affects direct support labor and hands-on labor, another 17% of the total recurring cost. DFA recognizes that assembly problems should be considered at early stages of product/part design.

Although there is much interest in having DFM and DFA techniques available on CAD/CAM systems, it is too late to make radical changes to a product once a design has been sufficiently detailed to enter it into the CAD/CAM system. To perform the early design analyses needed, computer software is available that evaluates the efficiency and assembly costs of a given assembly sequence. Since this analyses, which can occur even at the sketch stage, is of such potential benefit in the cost and technological areas, the implementation of this relatively inexpensive software could be of great benefit. The early information on the design of the product could also provide needed information to develop an efficient factory layout. With its data base design, this software would be compatible as a part of the master data base and would justify its cost with savings in areas such as materials, manufacturing, and tooling. The software could be easily accessed through the front-end expert system and would run on a computer being used for design purposes. This computer could be the local mainframe or one at a remote site.

DFM/DFA analyses is an important design activity where automated tools are applicable, but it is only a starting point in automating design. Product design includes CAD/CAM design, requirements analyses, documentation activities, scheduling, and information control. Sections 2.1 through 2.4 discuss automation strategies for these design activities.

2.1 CAD/CAM

The trend towards automated manufacturing processes makes simultaneous engineering between designers, process and manufacturing engineers, purchasing agents, marketers, accountants, and management vital. A three dimensional CAD/CAM system is yet another aspect of an overall CIM strategy. These systems would provide a wide variety of information for different users within a data base that would be included in the master data base for design and engineering information access through the front-end expert system.

The CAD/CAM system should be designed to help automate the product development process. It should be used through the full design cycle, from initial product design, modeling and drafting to factory floor layout, numerical control (NC) programming and robotic simulation and programming. An especially important feature that a CAD/CAM system should have in order to design products for automation and robotics is extensive solids modeling capabilities. The cost of CAD/CAM systems are dependent on the number of users, and therefore stations, which are needed in the design phase. The system could run from the local mainframe as did the DFM/DFA software or on another computer at a sight where design is being done. The cost of CAD/CAM systems is justified in that design for automation is extremely difficult without them and their proven contributions. Before a design is implemented on the CAD/CAM system, it should undergo the DFM/DFA analyses to achieve the maximum cost benefit.

Another tool in the CAD area is a structural analysis program to aid in building, displaying and viewing complex finite element models, finite element analysis and solving, system dynamics analysis, and assembling and analyzing objects. This software could also be run from the computer designated for design purposes and be accessed through the front-end expert system.

2.2 REQUIREMENTS ANALYSES

LRB general design information would be incorporated into the master data base both before and during the design process. Drawing "trees" as referred to in Figure 1.3-3 would allow traceability from smaller parts to larger parts of the LRB. This structure could be of further help in examining parts for requirements and government specifications because its tree structure allows easy traceability. Comparisons to determine compliance would be made by the expert system against the specifications and requirements which have been incorporated in the data base. Inherent checks would not allow a part which has not been found to be in compliance with all checks to become a part of a larger system. The expert system could log in change requests and show the effect that the change would have on areas such as cost and scheduling effects on the MRP II system. It also could determine if the change would be in conflict with any requirement or specification. This capability would insure that time is not wasted in examining unallowable configurations.

2.3 DESIGN DOCUMENTATION

All LRB design documentation, such as verification forms and checklists, notices of design decisions and changes, would be entered into the computer, thus alleviating much of the paperwork and those workers associated with it. Request and approval for change records on the computer would be a portion of these steps that would relieve much paperwork.

2.4 MANAGEMENT

As before mentioned, much information is available from the front-end expert system for General Dynamics, NASA, and others needing information. CAD/CAM drawings, requirements and change checklists, and design status for a given part are all pieces of information which allow management to make timely and accurate decisions which would affect not only design scheduling, but also scheduling for manufacturing activities being handled by the MRP II system, and test and flight operations readiness scheduling. The expert system could provide many methods of presenting requested information. Commands would be simple and processed immediately if possible.

2.4.1 SCHEDULING

A top-level scheduling capability would be available for designated individuals through the front-end expert system. This scheduler would set scheduling for design and could provide input to the MRP II scheduler. The input to the MRP II schedule would enable the scheduling ability within the MRP II package to begin.

2.4.2 INFORMATION CONTROL

A "checklist" of steps would be required in order to determine if a given LRB part has been designed to meet all specifications and requirements. This checklist may be queried at any time to determine how the design is progressing. Request for change would also generate a series of steps for making the actual changes. These would be entered into the data base as they were incorporated. A list of all changes which had been made to a given system would be available on request.

SECTION 3
PRODUCTION

A Manufacturing Resource Planning (MRP II) system is a beneficial strategy for automation of LRB production. MRP II is involved in indirect and direct support labor, material cost, and overhead cost. These areas comprise approximately 83% of total recurring cost, and an MRP II system can reduce costs in each of these areas. A good MRP II system can provide for a virtually paperless factory. This type factory has already begun to show that 70%-80% of paperwork can be eliminated, thereby allowing end-users to do faster and better quality work in their functional roles of production support, problem assessment, and decision making.

MRP II systems are common and therefore the technological risk is very low for them. USBI has an automated SRB processing system and General Dynamics has a paperless cruise missile assembly line. General Dynamics has several such systems which could possibly be accessed for use on the LRB, but until more is known about the LRB design it would be difficult to identify a specific MRP II system for this program.

What is needed within an MRP II package is the ability to conform with various government regulations as well as the build-to-requirement and actual job costing features of aerospace cost distribution. A full multilevel pegging ability is needed to contract with a project number, contract identifier, and accounting charge via Work Breakdown Structure (WBS) and Manufacturing Breakdown Structure (MBS). Traceability should be maintained by contract, task, subtask, part, lot/serial number and family. The ability for accumulating costs both incrementally and cumulatively by project and by order should also be included. These features are available on several MRP II systems.

The MRP II system would provide for master production scheduling, bill of materials, inventory control, materials management system, material requirements planning, shop floor control, purchasing management, cost management, and customer order entry. These capabilities will be discussed in sections 3.1 through 3.4 along with information on how the MRP II system could augment documentation and management activities.

3.1 AUTOMATED MANUFACTURING

Automated manufacturing begins with a good MRP II system. The system should be closed-loop and alleviate problems incurred when attempting such activities as updating changes to the data base in real time, interrelating information between different departments, and communicating information internally between different departments.

Since current estimates of LRB production rates appear to be relatively low, total automation would probably not be an option due to cost considerations. Hands-on labor is estimated to be only 7% to 12% of total recurring cost, so it is logical to assume that a great deal of money should not be spent on elaborate robotic and automated systems when only 7%to 12% of the cost is to be potentially affected. It would be best to automate procedures done only on a regular basis or those where the increased quality/safety can justify the cost. Use of machines or robots which do odd and rarely performed tasks should be avoided. Repetitive tasks are good candidates for automation because these are tasks which humans tend to make mistakes at while doing for long periods of time.

In a number of cases, automation requires that the MRP II portion of the master data base communicate with the portion containing design parameters. This could be achieved through low level interfaces between these two portions of the data base.

Two areas where automation is justified from a quality standpoint are engine and tank welding. Robotic welding is much more accurate than human welding and produces parameters which are important in that they can serve as proof of the integrity of the weld and thereby possibly alleviate some amount of inspection. Robotic welding is especially applicable to engine welds involving the fuel preburner, main combustion chamber, and the main injector, but it is estimated that as much as 80% of all engine welds could be done by a robot.

Another specific area in which robotics are extremely effective is automated storage and retrieval of needed tools; but an Automated Storage and Retrieval System (AS/RS) works best when it is busy most of the time and would only be implemented if this were the case. Automated Guided Vehicle Systems (AGVS) for waste control, work-in-progress, and tool delivery is another technology which would be highly efficient if it could be justified by cost savings. This is also the case with power clamping and automated load/unload of machine tools.

With all of the above mentioned technologies, the tendency to create "islands of automation," where different tasks are automated but not integrated, is inherent. This should be avoided because it negates the increases in productivity these types of systems are intended to provide. A major problem of creating a central control for these different types of automation, which in this case would be the master data base through the use of the MRP II system, is the interfacing of the robots/hard automation with the central system. In the case of robotic engine welds, the computer controlling the robot would have to communicate with the master data base for engine design information and the MRP II system would have to know the proper time to activate the welding system. Specific software for this activity would have to be developed. The added complication of incorporating these technologies means increased cost and technological risk factors, but they can supply increased quality with verification, alleviating some inspection. In some cases, quality improvements can offset implementation costs. With robotic welding this holds true, but the low production rate is a significant factor with regards to the other technologies. Substantial proof of increased quality and minimization of scrap/rework should be given before implementing an expensive technology when production rates cannot justify them from a cost standpoint.

3.2 AUTOMATED INTEGRATED LOGISTICS SUPPORT (ILS)

The MRP II system for LRB would provide for inventory control by processing material movement transactions with an on-line real-time updating system. This allows instantaneous access to part status information. The MRP II system would also support serialized part identification and standard two-step cycle counting to support inventory control and accuracy. A materials management system would provide on-line support for productivity improvements in the warehouse, in work-in-progress and in material delivery. To help with accounting and reporting, this system would relieve inventory at order/schedule release or at order/assembly completion. Material could be issued as units, in kits or in bulk and could be delivered to a cell or a particular workstation. Net change and regenerative Material Requirements Planning (MRP) would be provided by the MRP II system. The net-change system identifies changes in product structure and inventory status immediately and replans MRP daily. Only the affected parts would be expanded and netted to create a new material plan. A regenerative option would support periodic recreation of the material plan. An on-line purchasing system would follow the full scope of a material requirement from the time it became a purchase requisition through the release and printing of the purchase order and the receipt, inspection, and storage of goods. Orders could be handled on-line, and information such as where to ship, terms of agreement, and order acknowledgement would also be available. This order-entry capability might be covered by contract specification rather than an order entry sub-system because of low volume production.

3.3 DOCUMENTATION CONTROL

Control of acceptance documentation pertaining to the newly manufactured LRB would be an important task. The pre-designed "checklist(s)" would reside in the master data base for access during system verification procedures. The flight certification forms would also reside in the master data base for use when verification procedures have been completed. Complete verification and certification tracking would also be available.

3.3.1 SYSTEM VERIFICATION

In verifying the LRB system, customer requirements are the main driver in determining what automated technologies would or would not be allowed. With the LRB program, many automated production technologies produce parameters through in-process control that could alleviate some of either government or General Dynamics verification activities. Since there would be different types of verification associated with the different LRB systems, it would be difficult to identify which systems could or could not be automated. Vision systems using computers to acquire images from remote video cameras, perform analysis on the image and transmit information to other systems based on the analysis would be possible candidates for automated inspection if they are determined to be acceptable by the government. Unless this comes about and considering low production rates, it would not be cost effective to implement such a system for General Dynamics use only.

3.3.2 FLIGHT CERTIFICATION

Whatever means is decided upon for verification of a particular part or system, there would be formal documentation associated with its approval. Pre-designated forms should reside in the master data base and be available at inspection time. Instead of a signature of the person approving the inspection, the inspector could have a badge with a specific bar code which could be read into the computer when approval was given. This would alleviate much paper work and also enhance security in cases where important papers might be left lying around. Checklists for verification would reside in the master data base, and no system would be totally verified until all of its subsystems had made it through the verification checklist. Traceability of this list for any given system would be available upon request through the front-end expert system.

3.4 MANAGEMENT

By accessing the MRP II system through the front-end expert system, management would have information to make basic decisions and have them implemented in near real-time. The MRP II system would augment the ability to do this in some cases by simulating the effect of a particular change on manufacturing as a whole. Reports and information on various topics would be available on request. Monitoring of processes, centralized control and timely problem assessment are all made possible through the use of the MRP II system. Security would be enhanced because information would be stored in the computer and not on paper where it could possibly be lost. Access, both remote and local, would be tightly controlled through the use of passwords.

3.4.1 SCHEDULING/PLANNING

The master production schedule would be in terms of product configurations for specified quantities with specific due dates. It would work with material requirements planning subsystem of the MRP II and order entry subsystem for demand to become the basis for all other schedules. The master schedule is what drives the material requirements planning.

The production plan would be stored in the MRP II section of the master data base. This plan would be in terms of contract requirements or production philosophy. The production forecast would be the result of expanding and posting the high-level production plan to intermediate planning items and to real (master scheduled) items. The manual forecast would be available for the "master-scheduler" to input his ideas into the planning process. An on-line simulation would analyze the effects that certain variables would have on the plan.

3.4.2 INFORMATION CONTROL

In the area of shop floor control, the MRP II system would have work center routings to provide on-line maintenance of work center and routing information. Each assembly might have alternate routings. Resources could be assigned to an operation to measure capacity requirements over and above machine and labor requirements. Another capability in the area of shop floor control would be job progress reporting. This would provide capacity planning and schedule work orders for manufacturing. The critical ratio technique would be used to help job prioritizing and loading achieve maximum product utilization. Input/Output queue control, split orders, and variance reporting would be supported, as would the ability to provide contract/work order tracking by identifying parent/child relationships on split orders.

The bill of materials MRP II subsystem would provide basic MRP planning parameters, including those which the user has defined. All part master maintenance transactions would be on line and segregated by functional area for convenience. A material catalog would provide extensive part number cross referencing capability. Multiple bills of material would be available, and all bills of material would be maintained using an on-line work file to ensure security and efficiency prior to final update.

In the area of cost management, the MRP II system would use standard cost accounting to compare established standard costs with actual performance. A costed bill of materials would be developed incorporating incremental and cumulative cost roll-up. Standard versus actual variances would be reported against direct labor, direct material, and overhead at various levels. Direct costing would be possible through the segregation of costs into fixed and variable classifications. Inventory adjustments, historical cost inquiry, and responsibility accounting reports would also be available.

The MRP II system would provide an extensive document tracking utility which would be available for use in monitoring various approval levels and departmental checkpoints. Visibility of document status and departmental queues would provide timely information processing. Request for Offer (RFO) and vendor performance tracking would also be available.

3.4.3 LABOR CONTROL

The resource requirements planning subsystem of the MRP II system would check the production plan for medium- to long-range capital, capacity, and labor needs for the production effort. Gross units of measure such as direct labor hours required, test hours required, and number of liquid rocket boosters produced would be used by the MRP II system to come up with a proposed production plan. This plan could be analyzed by an on line simulation to determine required resources before committing material and labor dollars.

SECTION 4
GROUND OPERATIONS

Historical data shows that approximately 60 percent of the STS support manpower at KSC is involved in processing documentation. The cost for each page is approximately $1,000. This volume of paper degrades the quality of data and increases the chance for error in the analysis and decision making processes. Massive documentation requirements, inaccessibility of data, lack of real-time data, non-centralized operations and management, lack of configuration control, and approval/quality control/problem assessment are some of the major cost drivers. The LRB master data base would remove many of these cost drivers for the LRB system, helping to reduce overall STS costs significantly. Access to the system would be given to all personnel needing it, with security maintained through use of passwords.

The primary LRB ground operations functions - system test and checkout, inspection, vehicle assembly, and pre-launch operations (fueling, ordnance arming, etc.) - are all time and manpower intensive operations. Automation of these tasks would reduce processing time, minimize the critical path, and improve the overall safety and reliability of ground operations.

4.1 AUTOMATED TEST AND CHECKOUT

Until more is known about LRB design, many automated test and checkout procedures are difficult to identify, and the cost of developing many new technologies for the LRB might not be justified because of low launch rates. Vision systems are possible candidates for automated checkout if they are determined to be acceptable by the government. At sufficient launch rates, implementation of such a system would be cost effective.

An optical leak detection system for liquid engine processing identified in an Air Force Rocket Propulsion Laboratory study offers the potential for automating engine leak checks. This could provide significant benefits because of the frequency of these checks and the need to verify them. Such a leak detection system could provide pertinent data for the master data base, while insuring the integrity of the engine and removing the need for the manpower to perform this task.

An established technology in missile, air transport, and space systems which all LRB avionics would contain is the Built-In-Test (BIT). These systems would verify the integrity of the avionics system and identify any problem areas. The avionics would interface with the master data base to provide status and statistical data. Electronic power profile tests, pressurization system checks, and environmental control system checks are all candidates for automation dependent on further design information and cost justification. Automated fueling as demonstrated by the ET would be an automated pad operation for the LRB that would improve safety.

4.2 AUTOMATED INTEGRATED LOGISTICS SUPPORT (ILS)

The portion of the MRP II system used for ILS activities in the production environment could also be used in the ground operations environment. Again, the main interface would be to access the MRP II system through the front-end expert system. The same capabilities existing in the production environment automated ILS subsystem of the MRP II system also exist here.

4.3 DOCUMENTATION CONTROL

Since documentation costs are a major cost and efficiency driver in the ground operations tasks of inspection and assembly, automated information processing for these tasks is important. As with manufacturing, the pre-designed checklists for these tasks would reside in the master data base for access during system verification procedures. The flight certification forms would also reside in the master data base for use when verification procedures have been completed. Complete verification and certification tracking would also be available. Development of this ability within the front-end expert system is justified from a cost standpoint because use of the same ability in manufacturing would help defray investment requirements.

4.3.1 SYSTEM VERIFICATION

In verifying the LRB system, customer requirements are the main driver in determining what automated technologies would or would not be allowed. Automated checkout and/or the parameters it produces could eliminate or alleviate some of either government or General Dynamics verification activities. There would be different types of verification associated with the different LRB systems. It would take substantial effort to identify all the different systems and which could or could not be automated.

4.3.2 FLIGHT CERTIFICATION

Whatever means are decided upon for verification of a particular part or system, there is formal documentation associated with its approval. These pre-designated forms should reside in the master data base and be available at inspection time. Instead of a signature of the person approving the inspection, the inspector could have a badge with a specific bar code which could be read into the computer when approval was given or a specific password would identify the inspector. This would alleviate much paper work and also enhance security in cases where important papers might be left lying around. Checklists for verification would reside in the master data base, and no system would be totally verified until all of its subsystems have made it through the verification checklist. Traceability of this list for any given system would be available upon request through the front-end expert system.

4.4 MANAGEMENT

Since non-centralized operations and management is a major cost driver, the ability which the front-end expert system would have to provide management with information regarding design, production, and operations is invaluable. The system would handle requests for detailed information which would affect decision making, problem assessment and other management activities. Decisions could be implemented in near real time and "the big picture" of the program would be available. As each decision is implemented a record would be made, providing traceability of decisions. "What if" capability could be provided as a tool for assessing effects of a given decision. Reports and information on various topics would be available upon request.

4.4.1 SCHEDULING/PLANNING

Information from the master data base, such as design and production schedules, would allow scheduling for ground operations activities even in early stages of the program.

Scheduling would be provided by either the top-level scheduler or the MRP II scheduler with its wide range of scheduling abilities.

4.4.2 INFORMATION CONTROL

Status of LRB checkout, verification, certification, assembly and pre-launch operations would be available upon request to the master data base from the expert system. Checklists for the above procedures would be pre-entered into the data base at an early stage as possible in the LRB program and verifying these procedures would be done as much as allowable on the computer. This would provide the needed control of information and tracking ability.

4.4.3 LABOR CONTROL

Abilities in the area of labor control for ground operations would come from accessing the capabilities for this within the MRP II system.

SECTION 5
FLIGHT OPERATIONS

The following is a proposed system for flight operations diagnostics. An operational information interface to the master data base would be provided by the front-end expert system. This interface would reflect design intent, systems functionality, general design information, and operational procedures information. It would interface to an intelligent console during an LRB flight. Access to the near-real time data base, decommutation, and he master data base would be needed in order for the console operations to provide such output as seen in Figure 5-1.

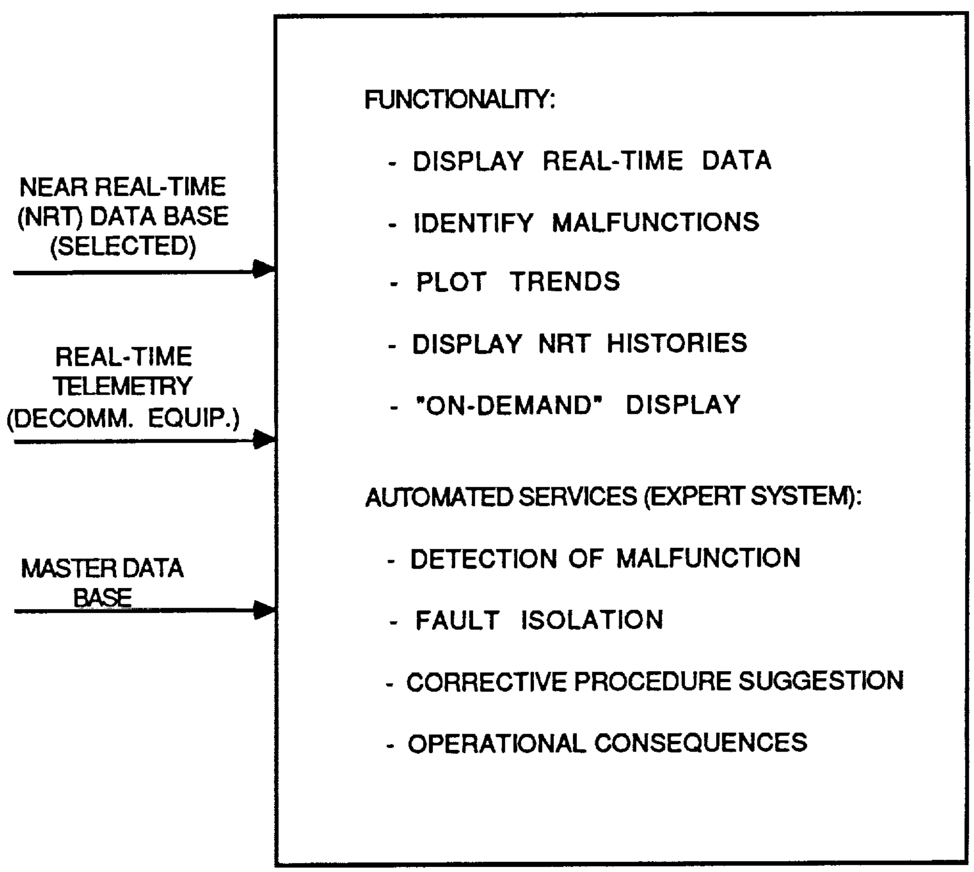


Figure 5-1. Console Operations

The above output would require an "intelligent" console, where a separate expert system would analyze data from the three sources mentioned. Figure 5-2 shows an example of console operation.

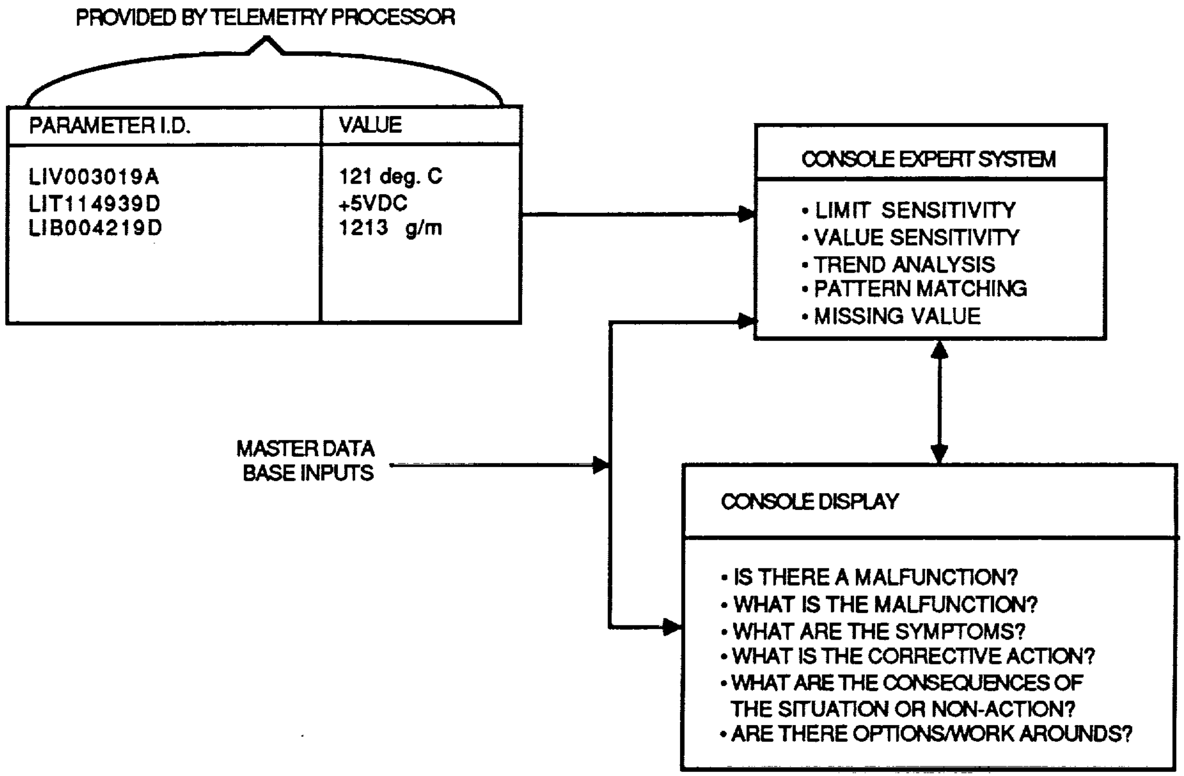


Figure 5-2 Example of Console Operations

Using drawings, diagrams, and other information from the master data base, the console display could be very graphic with problem areas highlighted. The user would be able to define objects or change definitions in real time. The console expert system would readjust the parameters mentioned in Figure 5-2 each time a decision, such as a design decision, affecting one of them occurs. This is called knowledge synthesis, and the technology to do this is only now emerging. Because of its high technological risk at this point, it would be better to "hard-code" the affected parameters into the system when a change would be made. The ability to perform the analysis would then exist without the technological risk. The above information would be invaluable in a crisis situation, and provide quick and accurate information for correcting any problem. This ability would justify the cost of the console and the console expert system.

SECTION 6
SYSTEM DEFINITION

The proposed LRB automated management and operations system would integrate the program from design to flight operations. The power of the system to provide the information for this would come not only from the great amount of information residing in the master data base, but also from the ability of the front-end expert system to present the information there in real-time and pertinent form. Data bases are common and powerful in themselves, but the expert system would provide centralized control over the program along with system relationship and tracking information in all areas. It also is the means for incorporating the CIM philosophy. The expert system would integrate the functions of the design, MRP II and operations hardware and software.

6.1 SUMMARY OF SYSTEM REQUIREMENTS

The major software needed to complete the system is as follows:

Data base software for master data base
Front-end expert system software
DFM/DFA analyses software
CAD/CAM and CAE (Computer Aided Engineering) software
MRP II software
Software for Robotic Welding (including interface)
Software for Optical Engine Leak Check
Operations Expert System Software
Network Software
Software interfaces for other automated
procedures

The major hardware needed to complete the system is as follows:

Local (front- end) mainframe computer
Computers for design purposes
Computers for MRP II work
Robot for engine welding
Visual Systems for Optical Leak Check
BIT hardware

If production and launch rates can justify usage of the following technologies, hardware and software would be needed to support them.

AS/RS
AGVS
Power clamp and automated load/unload
Electronic power profile tests
Pressurization system checks
Environmental Control System checks
Automated fueling

6.2 SCHEDULING AND COST

The time frame for developing the expert system would be from eighteen months to 2 years. This time frame is heavily dependent on the availability of the experts in all of the program phases for routine information to help in developing user interfaces to the data base. The availability of resources for optical leak check systems, robotic systems and automated fueling systems would also have to be investigated. Interfaces would also require development and test time. Most of the other technologies are available at this time. Time for integrating and testing all parts of the system is needed.

Preliminary costs for major hardware and software considerations are as follows:

SOFTWARE:	
Data base software for master data base	100K
Front-end expert system software (mostly software development cost)	2000K
DFM/DFA analyses software	1K
CAD/CAM and CAE (Computer Aided Engineering) software	136K
MRP II software	*
Software for Robotic Welding (including interface)	TBD
Software for Optical Engine Leak Check	TBD
Operations Expert System Software	TBD
Network Software	TBD
Software interfaces for other automated procedures	TBD

HARDWARE:	
Local (front- end) mainframe computer (includes some operating software)	250K
Computers for design purposes	TBD
Computers for MRP II work	TBD
Robot for engine/tank welding	TBD
Visual Systems for Optical Leak Check	TBD
BIT hardware	TBD

* Possible use of existing General Dynamics and NASA resources

APPENDIX 5

ENVIRONMENTAL ANALYSIS

NOTE:

THIS APPENDIX CONTAINS DATA REQUIREMENT NO.7,
ENVIRONMENTAL ANALYSIS.

UPDATE REPORT

ENVIRONMENTAL ANALYSIS

LIQUID ROCKET BOOSTER STUDY

July 12, 1988

Bar indicates changes or additions from last revision dated February 12, 1988

ENVIRONMENTAL ANALYSIS OUTLINE

I. Summary and Conclusions

The existing STS launch vehicle includes Solid Rocket Boosters (SRBs) which produce environmental impacts relative to noise, air quality, surface water and biological systems. Major impacts are associated with the ground cloud.

As an alternative to the SRBs, NASA is considering whether to introduce Liquid Rocket Boosters (LRB). This environmental analysis discusses the impacts of four potential LRB configurations relative to the existing SRB configuration. The LRBs and associated impacts are categorized by oxidizer/fuel combinations for the purpose of this analysis.

Final report will be updated to include recommendations regarding necessity for an environmental impact statement.

- LO_2/LH_2 impacts.
  - Reduced air quality impacts.
  - Reduced toxic cloud impact.
  - Reduced stratospheric ozone impacts.
  - Possible reduced noise impacts (thrust reduction).
  - Reduced water impact.

- Facility construction impacts.

- Increased probability of fuel handling accidents

- LO_2/CH_4 impacts.

  - Reduced air quality impacts ($>LO_2/LH_2$)

  - Reduced toxic cloud impact.

  - Reduced stratospheric ozone impacts ($> LO_2/LH_2$).

  - Possible reduced noise impacts (thrust reduction) ($> LO_2/LH_2$).

  - Reduced water impact.

  - Facility construction impacts.

  - Increased potential for fuel handling accidents.

- $LO_2/RP1$ impacts.

  - Reduced air quality impacts ($> LO_2/LH_2$).

  - Reduced toxic cloud impact.

- Reduced stratospheric ozone impacts (> LO_2/LH_2).

- Possible reduced noise impacts (thrust reduction) (> LO_2/LH_2).

- Reduced water impact (> LO_2/LH_2).

- Facility construction impacts.

- Increased potential for fuel spillage.

(Need discussion of areas of controversy.)

(Need conclusion on need for EIS.)

II. Purpose and Need

- Introduction

  - NASA will decide if it will proceed with advan Solid Rocket Boosters (SRB) for the Sp Transportation System (STS) or plan to introd Liquid Rocket Boosters (LRB).

  - SRBs appear to be advantageous due to a) simplic and b) compatibility with existing ground supp facilities.

  - LRB concepts are expected to be advantageous due a) superior performance b) safety, and environmental impacts.

  - This document is an environmental analysis impacts associated with using LRBs on the S program as compared to using existing SRBs.

- Relevance to national environmental policies.

  - Relevance to national environmental objectives.

    The National Environmental Protection Act (NEP sets forth the following as broad nation environmental objectives (sec. 101 [b]):

    1) Fulfill the responsibilities of each generatic as trustee of the environment for futu generations;

2) Assure, for all Americans, safe, healthful, productive, and aesthetically and culturally pleasing surroundings;

3) Attain the widest range of beneficial uses of the environment, without degradation, risk to health or safety, or other undesirable or unintended consequences;

4) Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of choice;

5) Achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and

6) Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

- Reduced environmental impacts associated with proposed systems.

III. Description of Proposed Action and Alternatives

- Introduction

As an alternative to existing Solid Rocket Boost (SRB) for the STS program, Liquid Rocket Boosters (L are being considered. This section describes different LRB configurations being considered.

The four alternatives are as follows:

1) LRB1: New pump-fed engine: (LO_2/RP1).

2) LRB2: New pump-fed engine: (LO_2/CH_4).

3) LRB3: New pump-fed engine: (LO_2/LH_2).

4) LRB4: New pressure-fed engine: (LO_2/RP1).

(See Table 1.)

While there are four alternatives being considered, they can be grouped into three alternatives by fu type for the purpose of evaluating environment effects. This results in a consideration of a liqu oxygen/RP1 alternative, a liquid oxygen/liquid metha alternative and a liquid oxygen/liquid hydrog alternative.

For a detailed description of the affected environmen refer to References 1 and 2.

Reference 1: Environmental Resources Document NASA, JF Kennedy Space Center, KSC-DF-3080, No 1986.

Reference 2: Environmental Impact Statement, Spac Shuttle Program, NASA TM-82278, April 1978.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 1

PERFORMANCE DATA - LRB ALTERNATIVES AND EXISTING SRB

	LRB1	LRB2	LRB3	LRB4	SRB
	LO_2/RP1 New Engine Pump Fed	LO_2/CH_4 New Engine Pump-fed	LO_2/LH_2 New Engine Pump-fed	LO_2/RP1 New Engine Pressure-fed	Existing Solid Booster
<u>Booster</u>					
Length (ft)	163	162	188	175	150
Diameter (ft)	13.2	13.1	15.3	14.2	12.2
Total Propellant (lbs)	1,045,000	794,000	567,000	1,126,000	1,110,000
GLOW (lbs)	4,128,707	3,642,000	3,226,855	4,404,468	4,500,000

IV. Environmental Impacts

Environmental impacts are discussed relative to a baseline established by the existing space shuttle operations using Solid Rocket Boosters. The purposed action consists of four alternatives described previously using LO_2/RP_1, LO_2/CH_4 and LO_2/LH_2 fuels: (1) a new pump-fed engine using LO_2/RP_1, (2) a new pump-fed engine using LO_2/CH_4, (3) a new pump-fed engine using LO_2/LH_2, and (4) a pressure-fed system using LO_2/RP1. An action alternative will consist of maintaining shuttle operations with existing Solid Rocket Boosters.

LO_2/LH_2 Fuels

- o Ground Level Air Pollution Effects.

  1) Primary products of combustion (H_2O).

  2) After cloud burning will result in limited formation of NO_X (acid rain?).

  3) No significant particulate/acid formation.

- o Stratospheric Ozone Effects.

  1) Elimination of CL_2 and Al_2O3 will decrease effect on ozone depletion.

  2) Ground operations using chloro-fluorocarbons/ freons. (Is there an increase here?)

- Noise

  1) Blast overpressures - required thrust levels appear to be reduced over existing system. May result in reduced noise levels associated with launch, if not offset by increased gas velocities.

  2) Sonic booms - slight effect anticipated due to size and weight changes.

- Water Pollution

  1) Significant reduction in impact of launch.

- Biological Impacts

  1) Blast overpressures expected to be reduced from present system. Impact on flora/fauna associated with blast may be slightly modified.

  2) Elimination of acid cloud and particulates will reduce impacts.

- Environmental Impacts from Potential Accidents.

  1) Fuel spills.

  2) Fires and radiation.

  3) Overpressure effects.

4) Explosive risks due to handling of increa amounts of LH_2 and LO_2.

<u>LO_2/CH_4 Fuels</u>

- o Ground Level Air Pollution Effects

    1) Primary products of combustion (CO_2, H_2O, N_2).

    2) After cloud burning will result in limit formation of NO_x, CO, etc.

    3) No significant particulate/acid formation.

- o Stratospheric Ozone Effects

    1) Elimination of CL_2 and Al_2O_3 will decrease effe on ozone depletion.

    2) Ground operations using chloro-fluorocarbons freons. (Is there an increase here?)

- o Noise

    1) Blast overpressures - required thrust levels appea to be reduced over existing system. May result i reduced noise levels associated with launch, if no offset by increased gas velocities.

2) Sonic booms - slight effect anticipated due to size and weight changes.

- Water Pollution

1) Significant reduction in impact of launch.

- Biological Impacts

1) Blast overpressures expected to be reduced from present system. Impact on flora/fauna associated with blast may be slightly modified.

2) Elimination of acid cloud and particulates will reduce impacts.

- Environmental Impacts from Potential Accidents.

1) Fuel spills.

2) Fires and radiation.

3) Overpressure effects.

4) Explosive risks due to handling of increased amounts of LO_2 and handling of CH_4.

LO_2/RP1 Fuels

- o Ground Level Air Pollution Effects

  1) Primary products of combustion are CO, CO_2, a H_2O.

  2) Decrease in launch ground cloud acid levels sir no Cl_2 and Al_2O_3 in exhaust gases.

  3) After cloud burning will result in limit formation of NO_X and SO_X.

- o Stratospheric Ozone Effects

  1) Elimination of Cl_2 and Al_2O_3 emission will ha decreased effect in O3 depletion.

  2) Ground operations using chloro-fluorocarbons/freo (Increased use on engines?)

- o Accoustical Noise

  1) Blast overpressures - required thrust level approximately the same as SRBs. Levels will b evaluated further as design is better defined.

  2) Sonic booms - no significant changes expected.

- o Water Pollution

    1) Less deposition of metals and acids into surface and ground water.

- o Biological Impacts

    1) Flora - Decrease impact on plant life due to lower acid deposition levels.

    2) Fauna - less impact on fish and wildlife due to lower toxicity levels of a exhaust clouds.

    3) Blast impacts are expected to be comparable.

- o Environmental Impacts from Potential Accidents.

    1) Fuel spills.

        - Hazardous waste impact (RP1).

    2) Fires and radiation.

Construction Impacts

The use of LRBs for the STS will result in major (in case of the use of LO_2/LH_2 or LO_2/CH_4 systems) and mi (in the case of the use of LO_2/RP1 systems) modificati to VAB assembly platforms. Additionally, varying degr of modification or construction will be required to fuel transfer/umbilical systems. Environmental impa associated with these construction efforts must be asses as the design is more definitized.

No-Action Alternative

In the event of no action, the STS would use the exist SRM. These impacts are discussed in detail in Reference 2.

V. Agencies and Individuals Contacted.

- To complete an environmental analysis, the followi agencies will need to be contacted. Addition agencies and individuals will be identified during t investigation.

  1) Environmental Officer, JF Kennedy Space Cente Florida.

  2) Environmental Officer, Vandenberg Air Force Bas California.

  3) Environmental Office, Headquarters Space Divisio Los Angeles, California.

  4) NASA/KSC biomedical office.

5) Florida office of Coastal Management, Department of Environmental Regulation, Tallahassee, Florida.

6) Bureau of Air Quality Management, Tallahassee, Florida.

7) US Environmental Protection Agency, Region 4, Atlanta, Georgia.

<u>SPECIFIC ANALYSIS REQUIRED FOR EA</u>

- Water vapor impact on stratosphere.
- Noise impacts (±).
- RP1 ground cloud ($CO - CO_2$).
- NO_2 generation differences LO_2/LH_2, $LO_2/RP1$, LO_2/C SRB.
- Fuel handling accidents (environmental consequences).
- Construction impacts.
- Possible increased use of chloro-fluorocarbons i cleaning.

<ins>LRB ENVIRONMENTAL IMPACT INCREMENTS</ins>

Fuel	LO_2/LH_2	$LO_2/RP1$	LO_2/CH_4
<ins>Launch</ins>			
Air quality	-	-	-
Noise	-	-	-
Water	-	-	-
Sonic Booms	-	-	-
Ozone	-	-	-
Biological	-	-	-
Construction	+	+	+
Fuel Handling Accidents	+	+	+

\+ Indicates increase with respect to SRB.

\- Indicates decrease with respect to SRB.